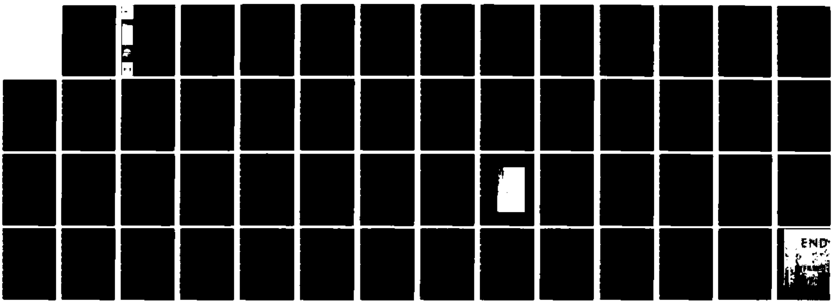
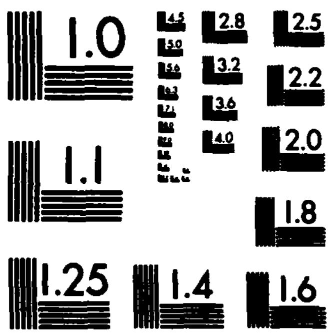
AD-A134 229 SITE CHARACTERIZATION AND DEBRIS MEASUREMENT IN THE JOINT MUNITIONS DUST..(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS ENVIR.. 1/1

UNCLASSIFIED J B MASON ET AL. SEP 83 WES/MP/EL-83-4 F/G 13/2 NL

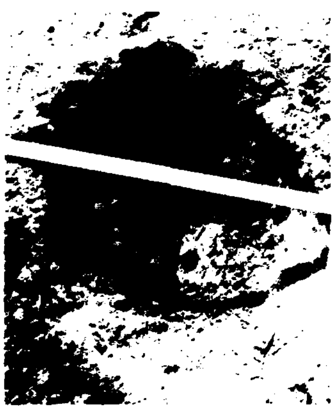




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

AD-A134 299



US Army Corps
of Engineers

MISCELLANEOUS PAPER EL-83-4

SITE CHARACTERIZATION AND DEBRIS MEASUREMENT IN THE JOINT MUNITIONS DUST TEST SERIES AT FORT POLK, LOUISIANA

by

James B. Mason and Katherine S. Long

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1983
Final Report

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Work Unit 002, Task Area B/E5,
Project No. 4A762730AT42

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper EL-83-4	2. GOVT ACCESSION NO. AD-A134	3. RECIPIENT'S CATALOG NUMBER 229
4. TITLE (and Subtitle) SITE CHARACTERIZATION AND DEBRIS MEASUREMENT IN THE JOINT MUNITIONS DUST TEST SERIES AT FORT POLK, LOUISIANA		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) James B. Mason and Katherine S. Long		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit 002, Task Area B/E5, Project No. 4A762730AT42
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE September 1983 13. NUMBER OF PAGES 49
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Debris
Dust control
Military operations
Munitions
Terrain

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A serious obstacle to the performance of electro-optical systems on the battlefield is the suspension of dust and other fine particulates in the air that interfere with optical propagation. Much of that material originates from the soil and vegetation cover of the terrain. This report presents the results of terrain characterization measurements made at Fort Polk, La., in April 1980, in support of a joint battlefield environment test series conducted by the U. S. Army Engineer Waterways Experiment Station and the U. S. Army Atmospheric

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Cont

20. ABSTRACT (Concluded).

Sciences Laboratory. Measurements of soil properties and explosion debris are presented and discussed.

A portion of the tests included the use of specially selected and prepared soil beds as sources of dust. Properties of those soils and some test results are also presented. These results are intended for application to the development of an improved obscurant source model for battlefield environment modeling.

PREFACE

The work described herein was part of a joint field test series, conducted in 1980 by the Environmental Laboratory (EL) and Structures Laboratory (SL) of the U. S. Army Engineer Waterways Experiment Station (WES) and the U. S. Army Atmospheric Sciences Laboratory (ASL) of the Materiel Development and Readiness Command. The SL portion, termed Munitions Bare Charge Equivalence (MBCE II) tests, was conducted under the direct supervision of Mr. L. K. Davis and the general supervision of Mr. L. F. Ingram, Chief of the Explosive Effects Division, and is being reported separately. Project Officer for the MBCE and person responsible for all explosive operations was Mr. C. E. Joachim. The ASL portion, termed Dusty Infrared Test-III, was conducted by Mr. Bruce Kennedy, Project Officer, under the general supervision of Dr. F. K. Niles, Chief of the Electro-Optical Systems Division, and is also being reported separately.

The EL portion, termed Battlefield Environments on Tailored Soils (BETS)-80B, was conducted by Mrs. K. S. Long under the direction of Mr. J. B. Mason and the general supervision of Dr. L. E. Link of the Environmental Systems Division (ESD). It was funded under Work Unit 002, Task Area B/E5, Project Number 4A762730AT42, entitled Improved Environment Realism for Battle Simulation, and is complemented by other ongoing tests and analysis under that work unit. These tests will be reported as subsequent parts in this series. Chief of ESD was Mr. B. O. Benn; Chief of EL was Dr. J. Harrison.

Commander and Director of WES during the publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Mason, J. E., and Long, K. S. 1983. "Site Characterization and Debris Measurement in the Joint Munitions Dust Test Series at Fort Polk, Louisiana," Miscellaneous Paper EL-83-4, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

SITE CHARACTERIZATION AND DEBRIS MEASUREMENT IN THE JOINT MUNITIONS DUST TEST SERIES AT FORT POLK, LOUISIANA

PART I: INTRODUCTION

Background

1. Airborne dust on the battlefield impedes the performance of personnel and equipment, but only recently have serious efforts been taken to understand and measure the separate mechanisms and properties that affect the generation of dust. These efforts are the result of the U. S. Army's increased use of advanced electro-optical (EO) technology. The performance of weapons and surveillance systems incorporating EO technology can be seriously impaired by heavy concentrations of airborne dust.

2. The activities that generate dust in battle are varied, but a correlative factor is the terrain. The terrain surface is the principal source of optically obscuring dust. This report attempts to describe quantitatively the role of terrain properties in controlling or contributing to dust loading by battle activities. The work described herein reflects a joint effort conducted at Fort Polk, La., in 1980, by two laboratories of the U. S. Army Engineer Waterways Experiment Station (WES)--the Structures Laboratory (SL) and the Environmental Laboratory (EL)--and the U. S. Army Atmospheric Sciences Laboratory (ASL) of the Materiel Development and Readiness Command. The SL portion, termed Munitions/Bare Charge Equivalence (MBCE II) tests, will be reported separately elsewhere (Joachim and Davis 1983). The ASL portion, termed Dusty Infrared Test-III (DIRT-III), is also being reported separately (Kennedy 1982). The portion of the work reported here is entitled Battlefield Environments in Tailored Soils (BETS)-80B.

Purpose and Scope

3. The general objective of both the MBCE II and the BETS tests was to measure the effects of various sizes of explosive charges on a select number of soil types with documented physical characteristics. MBCE II tests were conducted with various munitions and uncased charges on undisturbed native

soil, while the BETS tests were conducted on prepared test beds of soil with physical characteristics such as particle size distribution and moisture content having been determined previously.

4. A second objective of the EL personnel at the Fort Polk exercise was to characterize the test site for the other participants in the exercise. In response to the need to describe EO systems performance, computer models have been constructed to simulate realistic combat conditions. An important feature of those models is the description of the optical environment on the battlefield, using source models for dust production that require certain information about the terrain. EL's objective was to supply these terrain input data for use by ASL and other modelers in describing atmospheric transmission near munitions bursts. A further purpose of this work was the development of a terrain data base for extending the results thus obtained to other terrain conditions.

5. The EL scope of work included:

a. Preparation of a plan for tailored (specially prepared) soils tests and the acquisition and treatment of appropriate soils materials at WES.

b. Pretest survey and characterization of the test site at Fort Polk, La.

c. Assistance to the SL in the measurement at Fort Polk of soil and crater properties during the MBCE II portion of the test.

d. Transportation of soils and placement and preparation of tailored soils test beds at Fort Polk.

e. Sampling and measurement of craters, dust, and soil conditions during the BETS portion of the test.

f. Measurements of bulk soil samples at WES.

g. Analysis and assimilation of data at WES to determine the differences in dust potential of the various soils used in the explosive tests.

The results of the measurements made by various participants were shared mutually. Participants included, in addition to the three organizations named above, the U. S. Army Night Vision and Electro-Optics Laboratory (NVL), who measured 95-GHz transmittance and backscatter, and the Naval Research Laboratory (NRL), who measured visibility and infrared transmittance.

PART II: DESCRIPTION OF TESTS AND PROCEDURES

Site Description

6. The site used for these tests is located on Artillery Range 37 of the Fort Polk Military Reservation in west central Louisiana at approximately 31°03'N, 93°03'W and at elevation 75 m msl. That region lies within the Coastal Plain physiographic province; it is characterized by a topography of low relief dissected by frequent streams and forested primarily by longleafed (*Pinus palustris*) and loblolly (*Pinus taeda*) pines and secondarily by several deciduous varieties.

7. The test site illustrated in Figure 1 was prepared by clearing vegetation along and some 50 m to each side of an optical path of 1000-m length. The direction of the path was from SW to NE, and the explosive test area extended from 400 to 650 m along and 20 m to each side of the optical path as measured from the SW end. Plan and profile views of the test site are shown in Figure 2.

Test Plan Description

8. The two portions of the test series, MBCE II and BETS (also referred to as DIRT-III A and DIRT-III B, respectively), were conducted on 14-26 April and 28 April-1 May, respectively. The MBCE portion consisted of various artillery munitions and some uncased charges detonated statically for the purpose of examining the craters produced and relating them to their respective explosive charges. The BETS tests, on which most of the emphasis of this report lies, consisted of 43 uncased 2.27-kg explosive charges and one 4.54-kg uncased explosive charge. The majority of these events were detonated in a surface-tangent configuration (i.e., with the munition resting on ground surface) on prepared beds of selected soils. Table 1 provides the schedule and conditions for the individual rounds in each test.

9. Test monitoring and measurements other than those described here were performed as indicated in Table 2. Measurements were made of the dust and debris clouds in the optical paths of the various monitoring instruments to determine the effects of the clouds on optical propagation.

Description of Site Characterization Procedure

10. Several types of measurements were used by EL personnel to characterize the EO site. These are listed below with brief descriptive notes.

a. Cone index (CI). This test of soil strength was made by forcing a standard metal cone into the soil to a depth of 45 cm at a constant rate of penetration. The force required for penetration was indicated by the displacement of a micrometre gage and was read at 5-cm intervals. CI measurements were made throughout the the area at 50-m intervals and at selected craters as time permitted.

b. Moisture content (MC) and density. Soil mosture content is determined by taking the wet weight of a soil sample, drying the sample in an oven, and again weighing it to produce the ratio:

$$\frac{\text{wet weight - dry weight}}{\text{dry weight}}$$

A metal cylinder of standard size was used to obtain the soil sample, thus the volume is also known; therefore, the density (wet and dry) can be determined. MC and density measurements were obtained for representative locations prior to testing and at selected craters as time permitted.

c. Atterberg limits. This test determines the liquid limit and the plastic limit for a soil material. Those limits are the moisture contents at which the soils display liquid and plastic properties, respectively, as determined by specified tests. Since those tests are conducted in the laboratory, these properties are determined after the fact, using bulk samples collected from the test site.

d. Specific gravity. Specific gravity is the ratio of the weight of a specific volume of soil to the weight of that same volume of water.

e. Mineralogy. The mineral constituents of the soil were determined by X-ray diffraction.

f. Size gradation. Soil particle gradation tests are conducted by successive sieving using various sieve sizes down to mesh No. 200 (0.074 mm). Smaller sizes are analyzed in a hydrometer down to approximately a 2-μm diameter.

g. Crater dimensions. This information is obtained by measuring apparent crater depth and diameter (i.e., the visible boundaries of the fallback material) rather than the true crater boundary. The value of crater dimensions in estimating obscurant production has not been fully established, but the crater models u‵ed to esti ıate volume of ejected material require these dat

h. Soil classification. The soils used in these experiments were categorized by type using the United Soil Classification System (USCS) (U. S. Army Engineer Waterways Experiment Station 1953). Essentially, this system uses particle size gradation and Atterberg limits to place a soil in a specific classification. Classifications in this study were ML = inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity; SM = silty sands and silt-sand mixtures; CL = inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays; CH = inorganic clays of high plasticity; SP = poorly graded or gravelly sand with little or no fines; SC = clayey sands and sand-silt mixtures.

11. The soil sampling scheme carried out at Fort Polk was as follows. A preliminary survey of the site was conducted on 11 April before the start of testing. A grid of 80 by 180 m was laid out within the test area. Grid coordinates were measured in 10-m increments to the right (+Y) and left (-Y) side of the optical path as viewed in a northeasterly direction (+X), beginning with the instrumentation site at the SW end of the test area (see Figure 2). Native soil samples were collected to determine soil moisture, density, and bearing capacity throughout the area, and cone index was measured at selected points on this grid.

12. For each individual test, further characterization measurements were made. For the MBCE II, soil moisture samples were taken at each test poi.. just prior to firing and at crater depth just after firing. For the BETS, remolding cone index measurements were taken in the prepared soil bed just prior to firing.

13. Fourteen bulk samples of soil were obtained throughout the test period and were analyzed later for grain size, mineral content, and Atterberg limits. The locations and times of these samplings are given in Part III of this report.

Description of BETS Test

14. BETS tests were conducted at grid locations Y = 0 and -20 and X = 0, 20, 40, 60, and 80 . At each of these ten locations, a shallow pit of 1- to 2-cu-m volume was excavated by backhoe, lined with plastic film, and filled with the prepared soil. A 5- to 10-cm layer of the soil was then spread over the surface around this pit to a radius of 5 m. The soil in each pit was packed with the backhoe after placement After each test, the soil

test beds were restored in the same manner.

15. The soils chosen for this test were a heavy buckshot clay, a silt (loess), and a washed sand. The clay and silt (10 cu yd (7.6 cu m) of each) were obtained from WES in Vicksburg, Miss., dried, and transported to the site, arriving on 25 April; they were piled near the test area and covered to maintain dryness. The sand was obtained from a commercial supplier at Leesville, La., and stored similarly. The sand as delivered, however, contained appreciable moisture. More detailed data for these soils are presented later.

16. The BETS soil beds consisted of two each of the following soils: pure clay located at $X = 0$, pure sand at $X = 40$, pure silt at $X = 80$, a mixture of half clay and half sand at $X = 20$, and a mixture of half silt and half sand at $X = 60$. One bed of each soil was placed (a) directly beneath the optical path ($Y = 0$) and (b) 20 m to the left of the path ($Y = -20$). Testing began with these soils in the dry state, and measured quantities of water were added to the beds to produce increased moisture contents in succeeding tests; the soils were allowed to stand overnight after each addition of water. Mixed soils were prepared with a garden tiller in pits adjacent to the test area.

17. The native soil structure at the site consisted of a layer of yellow silty sand ranging to silt of nominal 30-cm thickness overlaying a red clay that ranged to sandy clay. Bulk samples from both the native and tailored soils were analyzed to determine classification, specific gravity, Atterberg limits, and organic content. Those results are presented in Table 3. Grain-size gradations are shown in Figures 3 through 14; Figure 15 compares representative gradation curves of the soils used in the testing.

PART III: PRESENTATION OF DATA

18. The results of the site characterization and the MCBE and BETS measurements are presented in this section. Other data obtained from this test series (see Table 2) will be reported by the agencies responsible for their acquisition. An exception was made in the case of precipitation data which are included here because of their effect on soil moisture; meteorological conditions during the test, including precipitation, will be published in detail by the ASL.

Site Characterization

19. A mineralogical analysis of the native soil was made using an X-ray diffraction spectrograph. The results are presented in Table 4. The lower clay layer (S-1) contained two prominent nonclay minerals, quartz and goethite, and a prominent clay, kaolinite. The goethite, a hydrous iron oxide, was probably responsible for the yellow to red color. Kaolinite is a clay mineral of low activity (not highly plastic), with a relatively low affinity for water; it was therefore not expected to exhibit highly cohesive properties.

20. The surface layer (S-2) was principally quartz, with traces of several clays and a small amount of potassium feldspar. Since it contained more than 50 percent quartz, it should have exhibited very little cohesion among grains even when wet; since it had a clay fraction that could reach 20 percent, it could provide significant obscurant material.

21. Similar results are shown in the table for the BETS soils identified as sand (SP), silt (ML), and clay (CH). As expected, the sand was virtually all quartz. The silt had a significant fraction of more active clay minerals, giving it greater plasticity than the native silt.

22. A compilation of the pretest moisture content, density, and cone index data taken for site characterization is given in Table 5. Grid locations and times of each sample collection are included. The table also contains some rainfall data obtained during the test period, not specific to the individual tests but relevant to surface moisture content. Some moisture data were obtained by mechanical means and not by comparing wet and dry sample weights (paragraph 10b). One of these was a Computrac moisture tester built

by Motorola Corporation that measures the drying rate of a small (few grams) sample of heated material; the other was a Speedy Moisture Meter built by Soiltest, Inc., that measures the pressure increase during desiccation of 40 gm of soil mixed with calcium carbide. Table 5 indicates which values were obtained by which method.

Soil and Crater Characteristics Measured for MBCE II and BETS Tests

23. Tables 6 and 7 list the pre- and posttest moisture content, density, and cone index data from samples taken relevant to the individual MBCE II detonations. Again, the results are shown in the order they were obtained. Notations of precipitation are given for reference to the surface moisture results. Table 8 contains similar data from the BETS test beds.

24. The crater dimensions for the two tests are given in Tables 9 and 10. Volumes have been calculated for the apparent craters, using the formula for a paraboloid of revolution:

$$\text{volume} = \frac{\pi D^2 d}{8}$$

in which d is the crater depth and D the mean diameter measured at the surface plane. Since the soil contained a stratigraphic boundary at about the 30-cm depth, the percentages of total volume above and below that level have also been computed for the MBCE II craters.

BETS Data

25. For the BETS test, ejecta collection pans 23 cm in diameter were placed on the surface usually 3, 5, and 7 m from the charge* on four radials--twelve pans for each shot. The material in the pans was collected after each shot and weighed. Table 11 shows the results by soil type in terms of the

---

* See Table 11 for pan distances used for each shot. In some instances ejecta were collected on flat panels measuring 61 by 122 cm which were placed 4 and 9 m from the charge. These results are identified in the table by entries appearing at those distances.

areal densities that were obtained by dividing the weights of material accumulated at the appropriate distances by the total collection pan area for those distances.

26. Figure 16 compares the average depths of ejecta for silt, sand, and a silt/sand mixture; the greatest depth was for the silt/sand mixture. One explanation of this phenomenon is that the relatively large sand particles become coated by the damp silt particles resulting in still larger particles. These larger particles weigh more and precipitate earlier and are thus found closer to the crater.

PART IV: DISCUSSION AND SUMMARY

Discussion

27. Because of the rainfall received during the first 2 weeks of the test, the surface moisture at the test site was elevated and variable; therefore, the moisture data in Table 5, obtained over a period of several days, are not directly comparable. In general, however, it appears that moisture and drainage conditions were uniform throughout the test area: when values measured in the surface layer (0-10 cm) of both the native soils and the tailored test beds were averaged for each day and the results compared to daily rainfall totals (see Figure 17), they show that a trend toward drying in the surface layer was in progress throughout the test period, though interrupted by occasional rainfalls. This trend was consistent with an increasing daily insolation as expected in April and May as the summer solstice approached.

28. The very heavy rainfall on 13 April recorded at the headquarters area several kilometers from the site was probably indicative of site conditions. It was probable that the surface layer was saturated during that event and that within a week, drying had lowered moisture contents to below 15 percent despite occasional traces of rain.

29. Moisture contents were generally higher in the clay layer underlying both the native and tailored soils. The number of samples obtained was much smaller, but moisture content values were consistently 3-6 percent higher than in the surface layer. Averaged values from depths of 50 to 100 cm appear in Figure 17; these samples were obtained from below the walls of craters, so they had undergone some consolidation. A few samples taken below the 100-cm depth contained lower moisture contents than did the 50- to 100-cm layer, but the number of samples was not sufficient for a significant comparison.

30. The size gradation data (Figures 3-5) show the surface layer of the native soil to be a silty sand with an average fines content (i.e., particles less than 0.074 mm in diameter) of 48 percent. The underlying clay had a fines content of 89 percent (see Figures 6-8), with 44 percent of particles smaller than 2 μm. Placement of these soils on the USDA classification chart is shown in Figure 18.

31. The dry density of the native soil surface layer was found to

range between 1.31 and 1.65, with a mean value of 1.52 and a standard deviation of 0.08. The 95 percent confidence interval for those data is from 1.50 to 1.55 gm/cc. Using a specific gravity of 2.63, these figures yield a range of voids ratios from 0.59 to 1.01. (The voids ratio is defined as the volume of voids divided by the volume of solids.)

32. The voids ratio affects the compressibility of the soil and thereby the crater volumes. When combined with water content, the air volume ratio (i.e. the compressible fraction of the soil) can be computed. For example, if saturation in the surface layer is 20 percent, the fraction of voids occupied by air is 80 percent, meaning that 48 to 80 percent of the soil volume consists of air.

33. It is difficult to estimate accurately dust loading from crater volumes because of soil compaction. Larger volumes are expected in lighter, more compressible material, but larger dust clouds may not necessarily follow. The compressibility of a soil depends on several properties including composition, water content, and loading history or preconsolidation. A compressibility coefficient C_c was used to evaluate the behavior of soils under static loads; although the coefficient is not intended for dynamic phenomena, it is probably suggestive of dynamic behavior. For many silts and clays, its value can be approximated from the liquid limit (Terzaghi and Peck 1948) in the following manner:

$$C_c = 0.009(LL - 10 \text{ percent})$$

Application of this expression to the soils tested here (Table 11) shows (a) the native subsurface layer had the highest compressibility of all soils tested and (b) the surface layer was essentially noncompressible. The relative contribution of compaction to crater volume for the BETS clay should be more than twice that for the BETS silt, but only about two thirds that for the native clay. In the latter case, the layered structure must be considered.

34. An independent method of determining relative amounts of munition excavation on the different soils was to compute ejecta volume based on measurements of ejecta. The data in Table 10 and Figure 16 were used for this as follows. The relationship of areal density (ρ in g/m^2) and distance (d in metres) was found to be in the form of $\rho = ae^{bd}$. The values corresponding

to each soil type are shown below, where r is the correlation coefficient:

BETS Soil Type	a	b	r^2
Clay	3.75	-0.64	0.70
Silt	1.17	-0.40	0.35
Sand	1.48	-0.52	0.73

Integrating each of the equations over the area on which the ejecta could fall (0 to ∞ m^2) yields the total mass of ejecta. To compute volumes to relate to the crater volumes of each soil type measured, divide mass by wet density. Because many of the ejecta are lost from the collectors due to bounce or air flow, an efficiency factor must be applied to the aforementioned equation. When these results were compared to those of Andrews (1977), that factor for dry sand was estimated to be 10.0; that is, only one tenth of the actual ejecta are collected. This factor was incorporated for all soils in the table below, although it was likely to vary for silt and clay.

BETS Soil Type	Mass g	Wet Density g/cc	Computed Ejecta Volume cc	Average Crater Volume cc	Difference Between Ejecta and Crater Volumes cc
Clay	57,500	1.85	310,810	365,000	54,190
Silt	45,900	1.45	316,550	356,000	39,450
Sand	34,400	1.85	185,940	262,000	76,060

35. The difference between the computed volume of ejecta and the measured volumes of the craters could have been caused by consolidation of material beneath the craters, which may have enlarged their dimensions. On the other hand, backfilling of a crater by ejecta may have reduced its dimensions. Since the relative amounts of consolidated and backfilled material were not known, these effects could not be included in the above calculation.

Summary

36. In April and May 1980, through a joint effort by the ASL and WES, a test series was conducted at Fort Polk, La., to learn the dust-producing effects of explosives in different soil types with different moisture regimes.

Both static-fired munitions and various weights of Composition-4 were used to produce these effects. The first part of the test series, MBCE, was conducted on 14-26 April and consisted of a variety of detonations in native soil. The second part of the tests, called BETS, was conducted on 28 April-3 May and consisted of uncased charges on a variety of soil conditions using sand, clay, and silt soils.

37. Site characterization included cone index, moisture content, plasticity index, soil particle size gradation, and crater dimensions. Ejecta from the BETS explosions were collected and weighed according to distance from the blast point. Equations of best fit were derived for each soil type and integrated to yield estimates of the excavated masses. The sand ejecta data produced the highest correlation.

38. Calculations comparing ejecta and crater measurements indicated that approximately 70 to 90 percent of the excavated volume of the apparent crater fell back as ejecta.

REFERENCES

Andrews, R. V. 1977. "Characteristics of Debris from Small-scale Cratering Experiments," in Roddy et al., eds., Impaction and Explosion Cratering, Pergamon Press, New York.

Joachim, C. E., and Davis, L. K. 1983. "Project MBCE: Munitions/Bare Charge Equivalence in Soils," Technical report in preparation, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Kennedy, B. W., compiler. 1982. "Data Report: Dusty Infrared Test III (DIRT-III)," U. S. Army Atmospheric Sciences Laboratory Report No. DR-82-0002, White Sands Missile Range, N. Mex.

Terzaghi, K., and Peck, R. 1948. Soil Mechanics in Engineering Practice, John Wiley and Sons, New York.

U. S. Army Engineer Waterways Experiment Station (WES). 1953. "The Unified Soil Classification System, Appendix A," Technical Memorandum No. 3-357, Vicksburg, Miss.

Table 1

Firing Log for Individual 2.27-kg BETS Rounds

Date (1980)	Time	Shot No.	Grid Location X, Y	Soil Type*	Moisture Content
28 Apr	1031	1	00, 00	CH	Dry
	1055	2	00, 20	CH	Dry
	1123	9	20, 00	CH/SP	Dry
	1145	10	20, 20	CH/SP	Dry
29 Apr	0734	5	00, 00	CH	Dry
	0758	6	00, 20	CH	Dry
	0821	14	20, 20	CH/SP	Dry
	0843	13	20, 00	CH/SP	Dry
	0913	4	80, 20	ML	Dry
	0935	3	80, 00	ML	Dry
	0936	11	60, 00	ML/SP	Dry
	1025	12	60, 20	ML/SP	Dry
	1216	7	80, 00	ML	Dry
	1239	8	80, 20	ML	Dry
	1306	15	60, 00	ML/SP	Dry
	1337	21	40, 00	SP	Dry
	1402	22	40, 20	SP	Dry
	1429	16	60, 20	ML/SP	Dry
30 Apr	0736	45**	60, 20	ML	Dry
	0807	24	40, 20	SP	Dry
	0833	23	40, 00	SP	Dry
	0901	33†	20, 00	Kaolin	Dry
30 Apr	0923	34†	20, 20	Kaolin	Wet
	0957	18	80, 20	ML	Moist
	1041	20††	80, 20	ML	Moist
	1122	17	00, 20	CH	Moist
	1233	19	00, 20	CH	Moist
	1304	46	40, 20	SP	Dry
	1328	39	20, 20	Kaolin	Moist
	1344	36	40, 20	SP	Moist
	1404	38	40, 20	SP	Moist
1 May	0750	26	00, 20	CH	Wet
	0830	30	00, 20	CH	Wet
	0858	28	80, 20	ML	Wet
	0924	32	80, 20	ML	Wet
	0955	35	40, 30	SP	Moist
	1023	37	40, 30	SP	Moist
	1057	43	60, 20	ML/SP	Dry
	1120	44	60, 20	ML/SP	Dry
	1241	42	60, 20	ML/SP	Dry
	1308	27**	80, 30	ML	Wet
	1339	31†	80, 30	ML	Wet
	1418	25	00, 30	CH	Wet
	1442	29	00, 30	CH	Wet

* According to the Unified Soil Classification System (U. S. Army Engineer Waterways Experiment Station (WES) 1953) (USCS): CH = inorganic clays of high plasticity; SP = poorly graded or gravelly sand with little or no fines; ML = inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.

** Buried tangent to the surface.

† Buried at a 15-cm depth.

†† Charge weight = 4.54 kg.

Table 2

Test Measurements and Performing Agencies

Measurement	Agency
Meteorology	ASL
Digital imagery	ASL
Particulate matter	ASL
Visibility, turbulence, and inversion	ASL
Survey	EL, WES
Soil characteristics	EL, WES
Crater size	EL, WES
Technical photography	WES
Timing	WES
Stereo photography	WES
95-GHz transmittance and backscatter	NVL
Visibility and infrared transmittance	NRL

Table 3

Fort Polk Representative Soil Analysis

Sample No.	Grid Location X, Y	Depth cm	Specific Gravity	Atterberg Limits*, %	USCS Classification**	Organic Content, %
				Native Soils		
1	00, 30	0-10	2.62	NP	Sandy silt (ML)	3.1
2	65, 40	0-10	2.64	NP	Silty sand (SM)	1.5
3	85, 20	0-10	2.68	NP	Sandy silt (ML)	4.2
4	50, 00	45-55	2.70	LL71, PL19, PI52	Clay (CH) with sand	6.6
5	60, 20	60	2.70	LL70, PL18, PI52	Clay (CH) with sand	6.0
6	85, 20	30	2.64	LL49, PL16, PI33	Sandy clay (CL)	1.8
				Tailored Soils		
7		Surface	2.66	LL50, PL17, PI33	Clay (CH)	5.4
8		Surface	2.64	NP	Sand (SP)	--†
9		Surface	2.68	LL35, PL11, PI24	Clayey sand (SC)	3.1
10		Surface	2.68	LL19, PL13, PI6	Silty sand (SM-SC)	1.5
11		Surface	--	LL25, PL22, PI3	Silt (ML)	--
12		Surface	2.68	LL49, PL28, PI21	Clay (CL)	--

* NP = nonplastic, LL = liquid limit, PL = plastic limit, PI = plasticity index.

** According to the USCS (WES 1953), ML = inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity; SM = silty sands and silt-sand mixtures; CL = inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays; CH = inorganic clays of high plasticity; SP = poorly graded or gravelly sand with little or no fines; SC = clayey sands and sand-silt mixtures.

† Not measured.

Table 4

Mineralogical Composition of Native and Tailored Soils by X-Ray Diffraction*

Constituents	Native Soils: Sample S-1	Native Soils: Sample S-2
Clays		
Chlorite	Rare	Rare
Kaolinite	Common	Rare
Clay-mica**	Minor	Rare
Vermiculite	Minor	Rare
Cronstedtite	Not detected	Minor†
Nonclays		
Quartz	Common	Abundant
Sillimanite	Probable	Rare
Potassium feldspar	Rare	Minor
Goethite	Common	Not detected

Constituents	Tailored Soils: Sample SP Sand	Tailored Soils: Sample ML Silt
Clays		
Smectite††	Rare	Common
Clay-mica**	Rare	Minor
Kaolinite group	Rare	Rare
Vermiculite	Not detected	Rare
Nonclays		
Quartz	Abundant	Intermediate
Dolomite	Rare	Minor
Mica	Not detected	Rare
Potassium feldspar	Rare	Rare
Plagioclase feldspar	Not detected	Minor

* Relative abundance is indicated as follows: abundant, >50 percent; intermediate, 25 to 50 percent; common, 10 to 25 percent; minor, 5 to 10 percent; rare, <5 percent.

** Clay-sized mica or illite or both.

† Tentative identification.

†† Swelling clay; the montmorillonite-saponite group.

Table 5

Pretest Soil Data Measured for Site Characterization, Fort Polk

Time Local	Grid Location X, Y	Depth cm	Moisture Content, %	Density, g/cc Wet	Density, g/cc Dry	Cone Index at Depth 0-15 cm	Cone Index at Depth 15-30 cm	Cone Index at Depth 30-45 cm
11 April 80, 19.4-mm rainfall, 1300-1500 hr								
0934	60, 20	0-10	10.9	1.70	1.55	325	510	325
0950	60, 10	0-10	16.5*	1.62	1.42	410	340	215
0950	60, 30	0-10	16.7	1.61	1.50	295	360	280
1009	70, 10	0-10	9.8	1.68	1.54	260	275	250
1015	70, 20	0-10	21.9	1.82	1.54	285	315	240
1037	70, 20	30-45	26.2	1.80	1.52			
1037	80, 10	0-10	9.2*	1.45	1.35	210	215	235
1109	80, 20	0-10	10.4	1.62	1.49	265	290	260
1109	80, 30	0-10	16.2*	1.63	1.40	220	240	235
12 April 80, 146.1-mm rainfall								
1507	80, 0	0-10	20.8**	1.82	1.51	285	345	285
1511	80, 20	0-10	18.8	1.81	1.42	130	210	230
1515	80, 40	0-10	23.7	1.92	1.55	95	175	270
1519	60, 20	0-10	13.4	--†	--	--	--	--
1528	60, 30	0-10	16.8	--	--	--	--	--
1533	70, 10	0-10	15.0	--	--	--	--	--
1538	80, 30	0-10	18.0	--	--	--	--	--
1543	80, 10	0-10	12.9	--	--	--	--	--
13 April 80, 25.4-mm rainfall								
14 April 80, 0.3-mm rainfall								
0802	70, 20	0-10	24.2*	--	--	--	--	--
1002	40, 20	0-10	17.3	1.82	1.56	145	215	185
1009	40, 40	0-10	20.5	1.78	1.48	115	170	250
1030	40, 5	0-10	20.4	1.86	1.54	265	365	175
1020	40, 40	2-10	20.5	1.78	1.48	115	170	205
1142	20, 20	2-10	15.2	1.77	1.54	160	175	180
		0-10	15.1	1.84	1.60	--	--	--
1150	20, 0	0-10	20.3	1.87	1.55	85	190	260
		2-10	21.3	1.85	1.56	--	--	--
1244	20, 40	2-10	19.0	1.82	1.53	105	115	165

(Continued)

* Computrac.
** Speedy Moisture Tester.
† Not measured.

Table 5 (Concluded)

Time Local	Grid Location X, Y	Depth cm	Moisture Content, %	Density, g/cc Wet	Density, g/cc Dry	Cone Index at Depth 0-15 cm	Cone Index at Depth 15-30 cm	Cone Index at Depth 30-45 cm
15 April 80								
0828	100, 0	0-10	15.7	1.89	1.63	140	235	260
0836	100, 20	0-10	14.6	1.68	1.47	115	215	215
0850	120, 20	3-15	23.2	1.85	1.50	100	190	265
0857	120, 40	3-15	19.7	1.86	1.55	130	215	315
0914	120, 0	0-10	21.4	1.90	1.57	120	215	265
0921	140, 0	0-10	16.7	1.81	1.55	145	240	290
0927	140, 20	0-10	14.7	1.79	1.56	135	255	270
0935	140, 40	0-10	27.6	1.78	1.39	150	200	160
1012	0, 0	0-10	14.3	1.88	1.64	115	245	295
1021	0, 20	0-10	15.3	1.90	1.65 max	225	295	200
1336	0, 40	0-10	13.1	1.79	1.58	110	115	220
0905	160, 0	0-10	18.1	1.84	1.56	165	275	425
0915	140, 60	0-10	15.4	1.77	1.53	140	200	270
0920	180, 60	0-10	16.3	1.91	1.63	145	170	190
16 April 80, 0.3-mm rainfall, 1400-1500 hr								
0934	160, 20	0-10	15.6	1.80	1.56	300	170	190
0937	160, 40	0-10	18.1	1.86	1.57	105	160	200
0945	160, 60	0-10	18.9	1.78	1.50	130	115	85
1002	180, 0	0-10	18.9	1.90	1.60	150	190	230
1010	180, 20	0-10	15.9	1.76	1.52	155	195	190
1015	180, 40	0-10	16.1	1.80	1.55	125	165	215
1248	60, 0	0-10	20.8	1.92	1.59	140	205	245
1255	60, 40	0-10	15.0	1.87	1.63	105	165	215
1301	60, 60	0-10	16.0	1.86	1.60	140	225	245
17 April 80, 15.9-mm rainfall, 1200-1500 hr								
0932	80, 60	0-10	14.5	1.50	1.31 min	160	190	260
0942	40, 60	0-10	13.4	1.52	1.34	125	175	315
0950	20, 60	0-10	16.8	1.87	1.60	125	170	260
1000	100, 60	0-10	19.0	1.78	1.50	125	215	260
1006	120, 60	0-10	19.1	1.70	1.43	90	115	150
1027	0, -20	0-10	18.0	1.87	1.58	125	185	240
1035	40, -20	0-10	20.3	1.81	1.50	115	205	365
1043	80, -20	0-10	19.9	1.81	1.51	125	180	275
1049	120, -20	0-10	21.0	1.81	1.50	140	180	230
1054	160, -20	0-10	20.8	1.80	1.49	160	245	320
1100	180, -20	0-10	21.2	1.73	1.43	175	235	290

Table 6

Soil Characteristics at Fort Polk MBCE Exercises

Time	Event	Location X, Y	Depth cm	Moisture Content, % Before Shot	After Shot	Density g/cc Wet	Dry
14 April 80, 0.3-mm rainfall							
1134	A1	70, 20	0-10	18.9	22.5	--*	--
--**	A1	70, 20	50-60	--	28.6	1.96	1.52
1130	A1	70, 20	60-70	22.3	22.5	--	--
1236	C1	60, 20	0-10	--	25.0	--	--
1235	C1	60, 20	Bottom	--	21.8	--	--
--	A3	70, 0	0-10	27.3	21.9	--	--
--	A3	70, 0	50-60	--	18.6	--	--
1601	C2	60, 10	0-10	22.9	25.0	--	--
1602	C2	60, 10	100-110	--	27.9	--	--
1355	A2	70, 10	0-10	16.4	23.3	--	--
1351	A2	70, 10	70-80	--	23.3	--	--
15 April 80							
1026	C3	60, 10	0-10	16.5	--	--	--
1312	B2	50, 10	0-10	17.8	19.6	--	--
1345	B2	50, 10	40-50	--	19.6	--	--
1324	B3	50, 0	0-10	17.8	--	--	--
1404	B3	50, 0	40-50	--	15.8	--	--
1410	D2	40, 10	0-10	20.4	14.1	--	--
1316	D2	40, 10	60-70	--	23.3	--	--
1714	D7	30, 0	0-10	17.1	15.3	--	--
--	D7	30, 0	110-120	--	18.1	--	--
1134	C3	60, 10	0-10	--	16.5	--	--
1135	C3	60, 10	60-70	--	23.4	--	--
1600	D3	40, 0	0-10	19.8	22.6	--	--
--	D3	40, 0	40-50	--	17.7	--	--
--	D3	40, 0	Bottom	--	23.9	--	--
16 April 80, 0.3-mm rainfall, 1400-1500 hr							
0857	B1	50, 20	0-10	18.9	16.0	1.88	1.58
--	B1	50, 20	20-30	--	16.0	--	--
1032	D7	30, 0	90-100	--	15.8	1.73	1.48
--	D7	30, 0	0-10	--	15.8	1.73	1.48
1312	C1	60, 20	50-60	16.3	19.9	2.01	1.68
1441	D1	40, 20	0-10	17.3	19.8	--	--
1440	D1	40, 20	40-50	--	21.7	--	--
1443	E1	80, 20	0-10	18.3	19.4	--	--
1527	E1	80, 20	40-50	--	21.8	--	--
1535	E4	90, 20	0-10	19.0	16.0	--	--
1611	E4	90, 20	50-60	--	23.6	--	--
17 April 80, 15.9-mm rainfall, 1200-1500 hr							
0903	E3	80, 40	0-10	--	14.3	--	--
0902	E3	80, 40	45-55	--	16.2	--	--
0909	E2	80, 30	0-10	17.8	16.0	--	--
0908	E2	80, 30	50-60	--	20.1	--	--
0920	D4	110, 20	0-10	18.3	16.3	--	--

(Continued)

* Not measured.
** No time recorded.

Table 6 (Concluded)

Time	Event	Location X, Y	Depth cm	Moisture Content, % Before Shot	After Shot	Density g/cc Wet	Dry
17 April 80, 15.9-mm rainfall, 1200-1500 hr (Continued)							
1122	B3	50, 0	0-10	21.9	25.3	--*	--
1108	B3	50, 0	45-55	--	32.8	1.91	1.44
1129	A1	70, 20	50-60	--	28.6	1.96	1.52
1300	D4	110, 20	100-110	--	21.3	--	--
1300	D4	110, 20	0-10	16.4	--	--	--
18 April 80, 1.6-mm rainfall, 1200-1400 hr							
0933	A5	90, 10	0-10	18.1	19.1	--	--
0953	A5	90, 10	115	--	19.8	--	--
1034	A6	90, 0	0-10	--	19.5	--	--
0926	D4	110, 20	0-10	20.3	16.8	--	--
0920	D4	110, 20	75	--	20.0	--	--
1310	D5	30, 20	0-10	16.1	--	--	--
--**	D5	30, 20	40-50	--	23.4	--	--
1330	D6	20, 20	0-10	15.2	--	1.77	1.54
1430	D6	20, 20	60	--	15.1	1.84	1.60
1215	C7	100, 10	0-10	--	19.3	--	--
19 April 80							
1235	B4	10, 20	0-10	--	17.6	--	--
1235	B4	10, 20	90	--	16.1	--	--
1340	B6	20, 10	0-10	--	12.5	--	--
21 April 80, 0.5-mm rainfall							
1520	E7	130, 10	0-10	16.6	--	--	--
--	E7	130, 10	85	--	15.6	--	--
1600	E8	130, 0	0-10	11.2	16.1	--	--
--	E8	130, 0	80	--	18.8	--	--
1600	E5	110, 10	0-10	18.3	14.5	--	--
--	E5	110, 10	90	--	20.5	--	--
1515	B8	120, 10	0-10	--	14.3	--	--
--	B8	120, 10	90	--	17.1	--	--
22 April 80, 5.7-mm rainfall, 1700-2400 hr							
1230	B5	140, 10	0-10	15.8	12.1	--	--
1230	B5	140, 10	100	--	19.7	--	--
1230	D8	140, 20	0-10	18.1	13.4	--	--
1505	D8	140, 20	120	--	18.0	--	--
1515	A9	150, 0	0-10	13.4	12.8	--	--
--	A9	150, 0	115	--	15.6	--	--
23 April 80, 21.1-mm rainfall, 000-0800 hr							
0900	B9	105, 20	0-10	13.6	13.5	--	--
0930	B9	105, 20	110	--	20.9	--	--
0930	C8	100, 30	0-10	14.5	20.4	--	--
1025	C8	100, 30	105	--	13.6	--	--
--	C9	110, 30	0-10	--	13.2	--	--
--	C9	110, 30	115	--	16.6	--	--

* Not measured.
** No time recorded.

Table 7

Cone Index Measurements for MBCE Exercises

Time	Event	Location X, Y	Cone Index, at Depth 0-15 cm	Cone Index, at Depth 15-30 cm	Cone Index, at Depth 30-45 cm
14 April 80, 0.3-mm rainfall					
0807	A1	70, 20	285	315	240
1216	A1	70, 20	115	170	205
1355	A2	70, 10	90	150	200
1356	A3	70, 0	95	120	195
1600	C2	65, 10	130	200	190
1602	C2	65, 10	75	85	135
1133	C3*	60, 10	110	165	150
1310	B2	50, 10	140	185	165
15 April 80					
1403	B3	50, 0	140	165	155
1315	D2	40, 10	200	190	175
1558	D3	40, 0	100	115	190
1712	D7	30, 0	300	605	550
16 April 80, 0.3-mm rainfall, 1400-1500 hr					
0855	B1	50, 20	150	170	180
1400	B1	50, 20	180	150	140
1405	D1	40, 20	175	215	200
1440	D1	40, 20	140	195	215
1526	E1	80, 20	165	220	240
1442	E1	80, 20	105	160	215
1600	E4	90, 20	120	195	240
1610	E4	90, 20	135	180	215
1620	E2	80, 30	205	255	265
17 April 80, 15.9-mm rainfall					
0901	E3	80, 40	95	235	450
0920	A4	110, 20	165	220	245
--**	A4	110, 20	160	200	230
1033	A6	90, 0	100	165	235
--	A8	100, 0	185	225	235
--	A8	100, 0	100	125	210
--	C7	100, 10	140	210	210
1214	C7	100, 10	150	190	225
1309	D5	30, 20	175	215	160
--	D5	30, 20	90	100	200
1300	D4	110, 20	135	190	250
18 April 80, 1.6-mm rainfall					
0925	D4	110, 20	125	200	250
0933	A5	90, 10	125	190	250
0952	A5	90, 10	115	140	210
--	A6	90, 0	150	200	250
1033	A6	90, 0	100	160	215

(Continued)

Note: n (preshot) = 36, average CI is 165, 230, 265.
n (postshot) = 41, average CI is 165, 230, 235.

* Test next day.

** No time recorded.

Table 7 (Concluded)

Time	Event	Location X, Y	Cone Index, at Depth 0-15 cm	15-30 cm	30-45 cm
18 April 80, 1.6-mm rainfall (Continued)					
1330	D6	20, 20	175	240	170
1430	D6	20, 20	100	85	150
--**	C5	30, 10	115	110	160
--	C5	30, 10	135	140	135
19 April 80					
--	C4	0, 20	250	325	185
--	C4	0, 20	185	190	200
--	B4	10, 20	190	200	160
1235	B4	10, 20	215	200	200
1235	B6	20, 10	150	125	190
1339	B6	20, 10	260	450	440
--	B7	20, 0	165	215	260
--	B7	20, 0	85	90	215
--	D9	15, 11	240	665	750
--	D9	15, 11	340	500	490
21 April 80, 0.5-mm rainfall					
--	C6	130, 20	115	135	200
--	C6	130, 20	100	110	185
1520	E7	130, 10	175	210	275
1550	E7	130, 10	180	225	320
1600	E8	130, 0	175	250	260
1630	E8	130, 0	190	215	265
1600	E5	110, 10	175	240	250
1710	E5	110, 10	160	175	225
--	A7	120, 20	160	225	215
--	A7	120, 20	90	140	240
1514	B8	120, 10	190	165	275
--	B8	120, 10	140	165	200
22 April 80, 5.7-mm rainfall					
--	B5	140, 10	200	300	385
1230	B5	140, 10	150	235	325
1229	D8	140, 20	185	270	290
1420	D8	140, 20	100	185	265
1450	E6	140, 10	150	235	360
--	E6	140, 10	110	175	300
1515	A9	150, 0	215	290	325
1620	A9	150, 0	125	210	275
23 April 80, 21.1-mm rainfall					
0900	B9	105, 20	145	210	235
0930	B9	105, 20	160	175	185
0930	C8	100, 30	235	200	190
1025	C8	100, 30	200	200	210
--	C9	110, 30	190	210	240
--	C9	110, 30	190	215	210

** No time recorded.

Table 8

Pre- and Posttest Soil Characteristics for BETS Test

Time	Event	Soil Type*	Location X, Y	Moisture Content, % Before Shot	Moisture Content, % After Shot	Density, g/cc Wet	Density, g/cc Dry	Remolding Cone Index
28 April 80								
1031	TS-1	CH	05, 0	--**	--	--	--	Too dry
1055	TS-2	CH	05, 20	--	--	--	--	Too dry
1123	TS-9	CH/SP	25, 0	--	--	--	--	Too dry
1145	TS-10	CH/SP	25, 20	--	--	--	--	Too dry
29 April 80								
0734	TS-5	CH	05, 0	3.0	--	--	--	--
0758	TS-6	CH	05, 0	3.0	--	--	--	--
0821	TS-14	CH/SP	25, 0	--	--	--	--	--
0843	TS-13	CH/SP	25, 20	--	--	--	--	--
0915	TS-4	ML	85, 20	10.4	--	1.70	1.54	--
0930	TS-3	ML	85, 0	9.9	--	1.66	1.51	--
0945	TS-11	ML/SP	65, 0	--*	17.4	1.86	1.58	--
1145	TS-10	CH/SP	25, 20	--	--	--	--	--
1005	TS-12	ML/SP	65, 20	16.2	--	2.00	1.73	2.18
1200	TS-7	ML	85, 0	--	15.2	1.28	1.11	--
1225	TS-8	ML	85, 20	7.5	--	1.44	1.34	--
1247	TS-15	ML/SP	65, 0	6.8	--	1.78	1.67	--
1337	TS-21	SP	45, 0	3.4	--	1.63	1.58	--
1345	TS-22	SP	45, 20	4.2	--	1.69	1.63	--
1410	TS-16	ML/SP	65, 20	--	6.4	1.80	1.69	--
30 April 80, 0.3-mm rainfall								
0755	TS-24	SP	45, 20	3.0	--	1.61	1.57	--
0819	TS-23	SP	45, 0	3.1	--	1.61	1.56	--
0835	TS-33	CL	25, 0	0.5	--	0.47	0.47	--
--†	TS-34	CL	25, 20	--	--	--	--	--
0945	TS-18	ML	85, 20	24.4	--	1.77	1.42	--
1041	TS-20††	ML	85, 20	2.6	--**	1.78	1.74	2.77
1122	TS-17	CH	05, 20	17.2	--	1.76	1.50	1.36
1225	TS-19	CH	05, 20	4.6	--	1.50	1.44	--
1250	TS-46	SP	45, 20	3.1	--	1.68	1.63	--
1340	TS-36	SP	45, 20	10.2	--	1.77	1.61	--
1356	TS-38	SP	45, 20	8.7	--	1.72	1.58	--
1 May 80, 4.2-mm rainfall								
0750	TS-26	CH	05, 20	--	--	--	--	0.86
0822	TS-30	CH	05, 20	--	--	--	--	--
0858	TS-28	ML	85, 20	26.9	--	1.94	1.53	1.13
0915	TS-32	ML	85, 20	24.0	--	1.89	1.52	0.56
1010	TS-35	SP	45, 30	10.7	--	1.57	1.42	4.68
1023	TS-37	SP	45, 30	8.8	--	1.67	1.53	9.64
--†	TS-43	ML/SP	65, 20	5.6	--	1.82	1.72	Too firm
1225	TS-42	ML/SP	65, 20	7.9	--	1.70	1.58	1.63
1250	TS-27	ML	85, 30	9.9	--	1.74	1.58	--
1330	TS-31	ML	85, 30	9.5	--	1.77	1.62	2.43
1410	TS-25	CH	05, 30	22.7	--	1.84	1.50	1.23
1435	TS-29	CH	05, 30	24.6	--	1.85	1.48	1.25
--	TS-44	ML/SP	65, 20	7.6	--	1.72	1.60	--

* See Table 3 for USCS soil classifications.
** Not measured.
† No time recorded.
†† 10-lb shot.

Table 9

MBCE Crater Parameters

Event	Munition/Bare Charge Size and Configuration*	Depth, d cm	Diameter, D N/S cm	Diameter, D E/W cm	Volume m^3	Volume, % Above 30 cm (Silt)	Volume, % Below 30 cm (Clay)
A1	155-mm ST	48	230	250	1.09	88	12
A2	155-mm ST	45	240	220	0.93	92	8
A3	155-mm ST	52	250	250	1.28	84	16
A4	155-mm STB	100	330	340	4.02	45	55
A5	155-mm STB	115	160	160	1.16	48	52
A6	155-mm STB	105	170	160	1.12	52	48
A7	155-mm SB	125	460	460	10.39	23	77
A8	155-mm SB	170	190	170	2.16	30	70
A9	155-mm DB	115	420	440	8.35	29	71
B1	105-mm ST	35	140	150	0.29	99	1
B2	105-mm ST	33	120	120	0.25	100	0
B3	105-mm ST	40	150	128	0.40	97	3
B4	105-mm STB	90	190	160	1.08	60	40
B5	105-mm SB	90	290	310	3.18	51	49
B6	105-mm STB	70	170	180	0.84	73	27
B7	105-mm STB	90	190	160	1.08	60	40
B8	105-mm SB	90	320	300	3.40	50	50
B9	105-mm DB	110	290	300	3.76	42	58
C1	57.87-kg C-4** ST	70	240	230	1.33	70	30
C2	57.87-kg C-4 ST	73	220	230	1.45	68	32
C3	57.87-kg C-4 ST	65	200	180	0.92	76	24
C4	33-kg C-4 STB	120	260	280	3.44	40	60
C5	33-kg C-4 STB	115	180	160	1.31	48	52
C7	33-kg C-4 SB	150	380	360	8.06	26	74
C8	33-kg C-4 DB	105	460	470	8.92	27	73
C9	33-kg C-4 DB	115	480	440	9.56	26	74
D1	122-mm ST	40	170	170	0.45	97	3
D2	122-mm ST	50	160	240	0.79	88	12
D3	122-mm ST	40	150	180	0.43	97	3
D4	122-mm STB	75	90	90	0.24	73	27
D5	122-mm ST	80	120	100	0.38	69	31
D6	122-mm STB	60	140	90	0.31	83	17
D7	122-mm STB	100	300	330	3.90	45	55
D8	122-mm SB	120	340	380	6.11	34	66
D9	122-mm STB	70	140	140	0.54	74	26
E1	152-mm ST	60	200	180	0.85	80	20
E2	152-mm ST	45	190	180	0.60	93	7
E3	152-mm ST	45	210	220	0.82	92	8
E4	152-mm ST	60	190	190	0.85	80	20
E5	152-mm STB	90	320	290	3.29	51	49
E6	152-mm STB	70	320	310	2.73	62	38
E7	152-mm STB	85	330	340	3.75	51	49
E8	152-mm STB	80	320	360	3.63	53	47

* ST = surface tangent (with munition resting on ground surface); STB = surface-tangent buried (buried directly below ground surface); SB = shallow buried (buried 0.76 m below ground surface); DB = deep buried (buried 1.5 m below ground surface).

** Composition-4.

Table 10

BETS Crater Parameters

2.27-kg Shot Event	Soil Type*	Depth, d cm	Diameter, D E/W cm	Diameter, D N/S cm	Volume m^3
TS-1	CH	30	170	190	0.38
TS-2	CH	25	190	160	0.30
TS-3	ML	25	100	100	0.10
TS-4	ML	30	90	100	0.11
TS-5	CH	30	140	160	0.27
TS-6	CH	32	150	145	0.21
TS-7	ML	30	110	110	0.41
TS-8	ML	30	100	90	0.11
TS-11	ML/SP	40	180	135	0.39
TS-12	ML/SP	48	130	130	0.32
TS-13	CH/SP	28	140	120	0.19
TS-14	CH/SP	30	150	140	0.25
TS-15	ML/SP	28	80	90	0.08
TS-16	ML/SP	33	110	120	0.17
TS-17	CH	48	125	130	0.31
TS-18	ML	48	175	180	0.59
TS-19	CH	42	150	140	0.36
TS-20**	ML	50	200	200	0.79
TS-21	SP	32	140	130	0.23
TS-22	SP	29	140	145	0.23
TS-23	SP	33	150	140	0.27
TS-24	SP	25	300	150	0.50
TS-25	CH	38	117	122	0.21
TS-26	CH	55	175	180	0.68
TS-27	ML	45	190	200	0.67
TS-28	ML	49	146	146	0.41
TS-29	CH	50	140	130	0.36
TS-30	CH	43	120	120	0.24
TS-31	ML	50	180	180	0.64
TS-32	ML	60	160	190	0.72
TS-33	Kaolin	30	150	140	0.25
TS-34	Kaolin	33	170	170	0.37
TS-35	SP	20	137	122	0.13
TS-36	SP	25	150	155	0.23
TS-37	SP	28	150	140	0.23
TS-38	SP	25	130	150	0.19
TS-39	Kaolin	35	160	155	0.34
TS-42	ML/SP	28	90	100	0.10
TS-43	ML/SP	36	142	124	0.25
TS-44	ML/SP	63	175	180	0.78
TS-46	SP	22	200	200	0.35

* See Table 3 for USCS soil classifications.

** 10-lb C-4.

Table 11

BETS Ejecta Densities by Soil Type

Event	Areal Density, g/m^2, at Distances, m					
	2	3	4	5	7	9
			Clay			
TS-1	1396.1	126.7	85.9			
TS-2	2956.0	123.6	107.2			
TS-5		289.9		56.0	19.8	
TS-6		152.9		188.2	12.2	
TS-17		847.9		182.7	74.9	
TS-19		883.8		164.5	60.9	
TS-26		5182.9		754.7	79.2	
TS-25		530.7		201.4	120.3	47.0
TS-29		1535.7		190.7	41.7	27.0
			Silt			
TS-4		240.6		88.3	49.9	
TS-3		206.5		53.6	25.6	
TS-7		47.5		71.3	32.9	
TS-8		114.5		60.9	92.0	
TS-18		450.7		292.4	49.3	
TS-20		3520.1		344.5	91.4	
TS-28				353.2	193.0	
TS-32				159.4	115.9	
TS-27				644.8	172.4	5.9
TS-31				38.4	14.7	28.0
			Sand			
TS-21		256.4		37.2		
TS-22		160.8		49.9	33.5	
TS-24		1001.4		82.8	60.9	
TS-23		530.5		84.1	22.5	
TS-46		763.2		151.1	16.4	
TS-35				65.2	42.9	24.1
TS-37				135.2	45.1	25.6
			Silt/Sand Mixture			
TS-11		445.3		162.6	44.5	
TS-12		156.5		143.1	46.9	
TS-15		265.0		212.0	25.6	
TS-16		275.3		81.6	26.8	
TS-43		1838.2		528.2	145.9	
TS-44		2943.4		780.8	210.0	
TS-42		1057.0		93.0	14.3	11.67
			Clay/Sand Mixture			
TS-9		525.1	335.0			
TS-10		699.3	339.9	290.6		
TS-14		224.8	107.2	35.3		
TS-13		1122.6	77.4	150.5		

Table 12

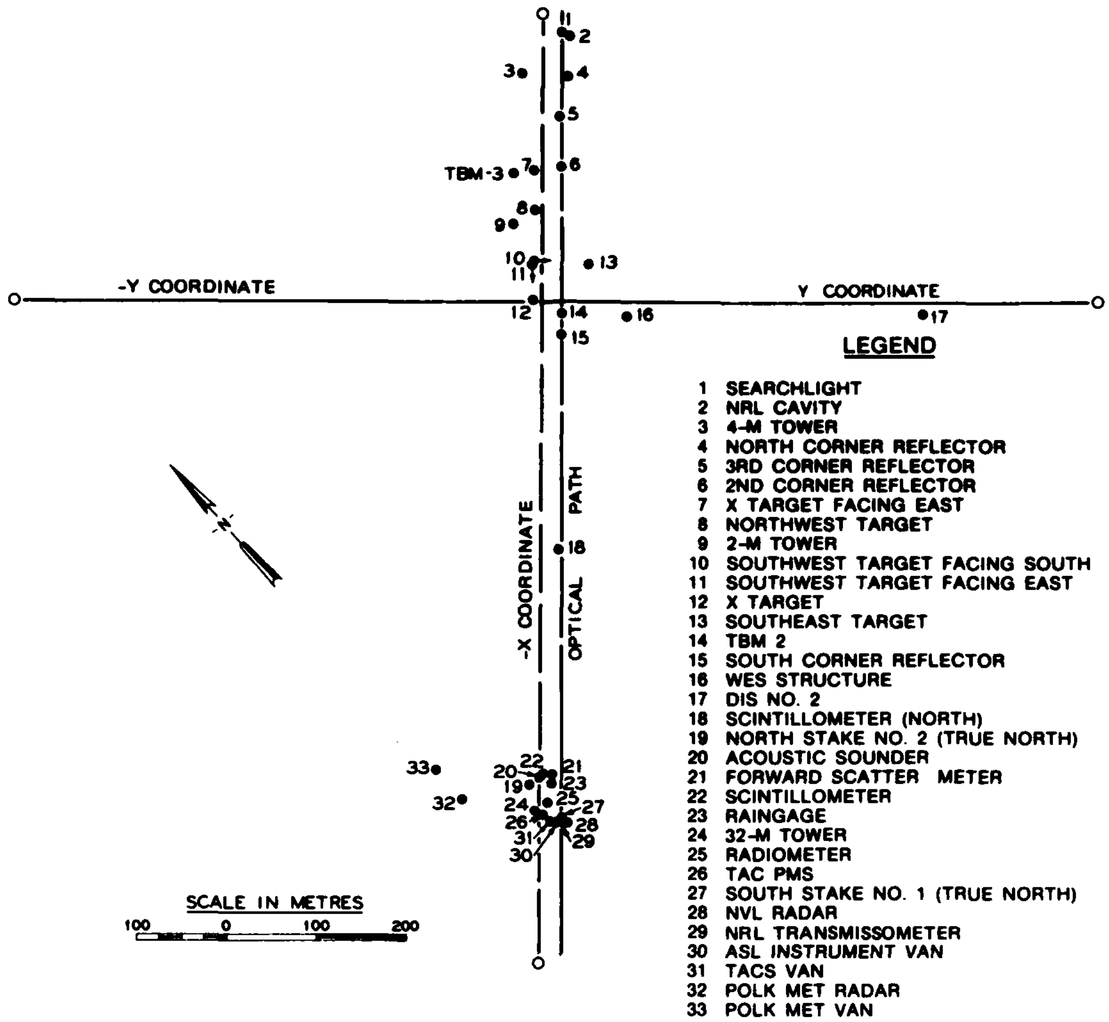
Derived Properties of BETS and Fort Polk Soils

Soils	Average Density g/cc Wet γ_w	Dry γ_d	Average Water Content* %, ω	Average Air Volume* V_a, %	Compressibility Coefficient C_c	Plasticity Index
Native silty sand 0-30 cm	1.83	1.56	17	14	N/A	0
Native clay >30 cm	1.93	1.56	24	4.8	0.55	50
BETS clay	1.82 1.50	1.49 1.44	22 4	--** --	0.36	33
BETS silt	1.87 1.52	1.49 1.42	26 7	-- --	0.16	12
BETS sand	1.68 1.64	1.57 1.57	7 4	-- --	N/A	0
Clay + sand	--	--	--	--	0.23	24
Silt + sand	--	1.67	--	--	0.08	6

* Water content $w = 100\left(\frac{\gamma_w - \gamma_d}{\gamma_d}\right)$; air volume $V_a = 100\left(1 - \frac{\gamma_d}{G_s} - \frac{\omega\gamma_d}{100}\right)$.

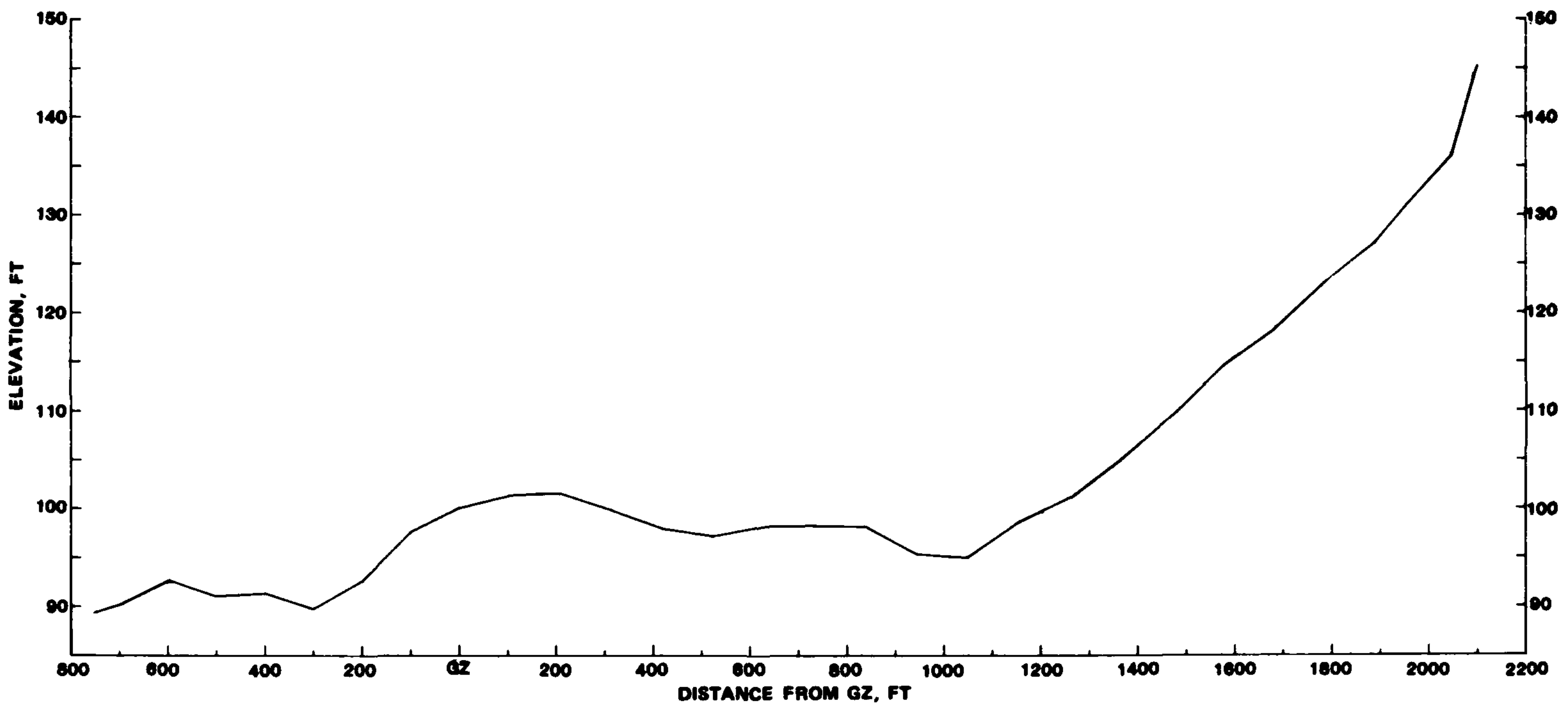
** Not measured.

Figure 1. BETS test site



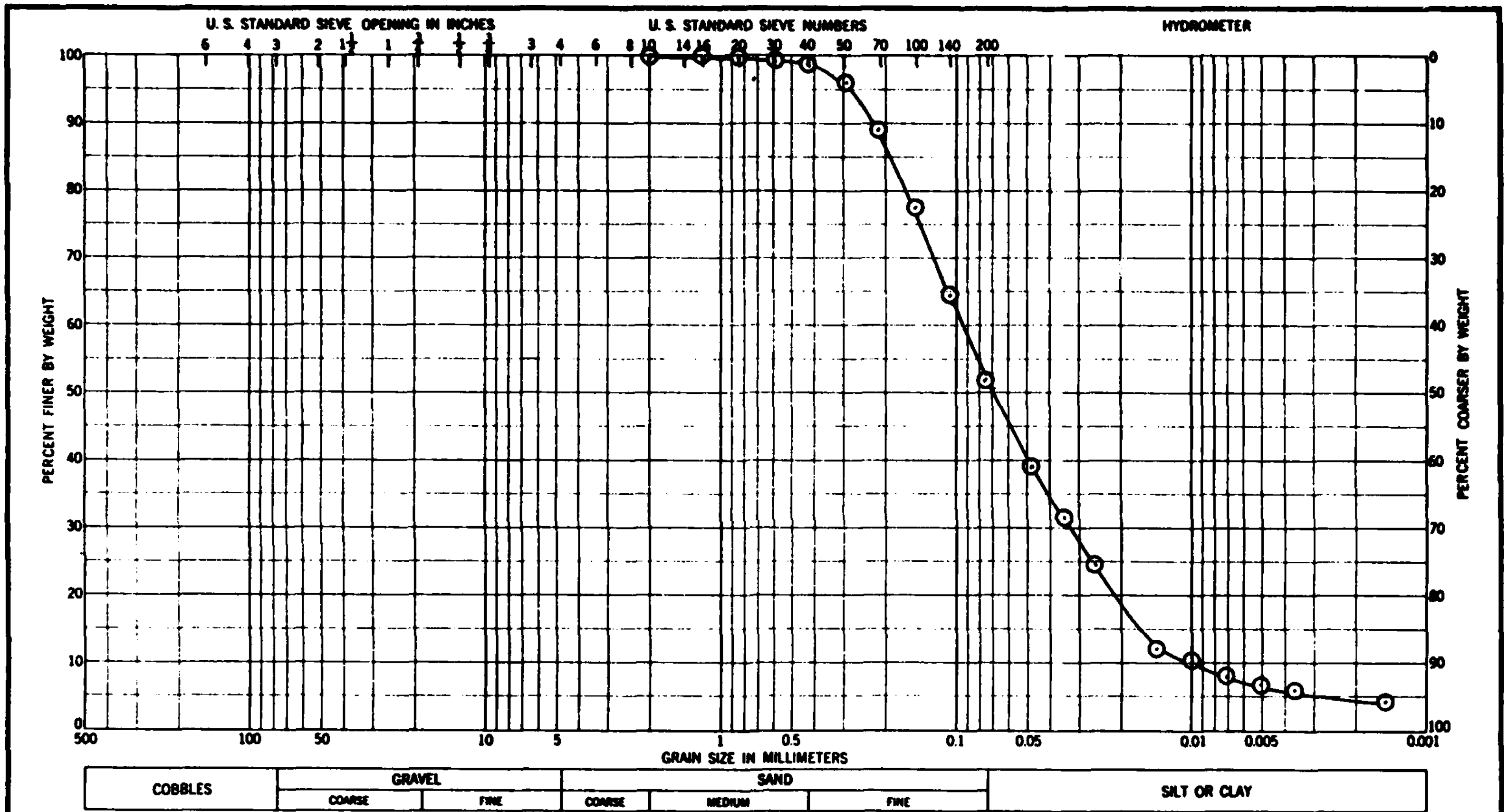
a. Plain view

Figure 2. Schematic of BETS test site (Continued)



b. Profile view

Figure 2. (Concluded)

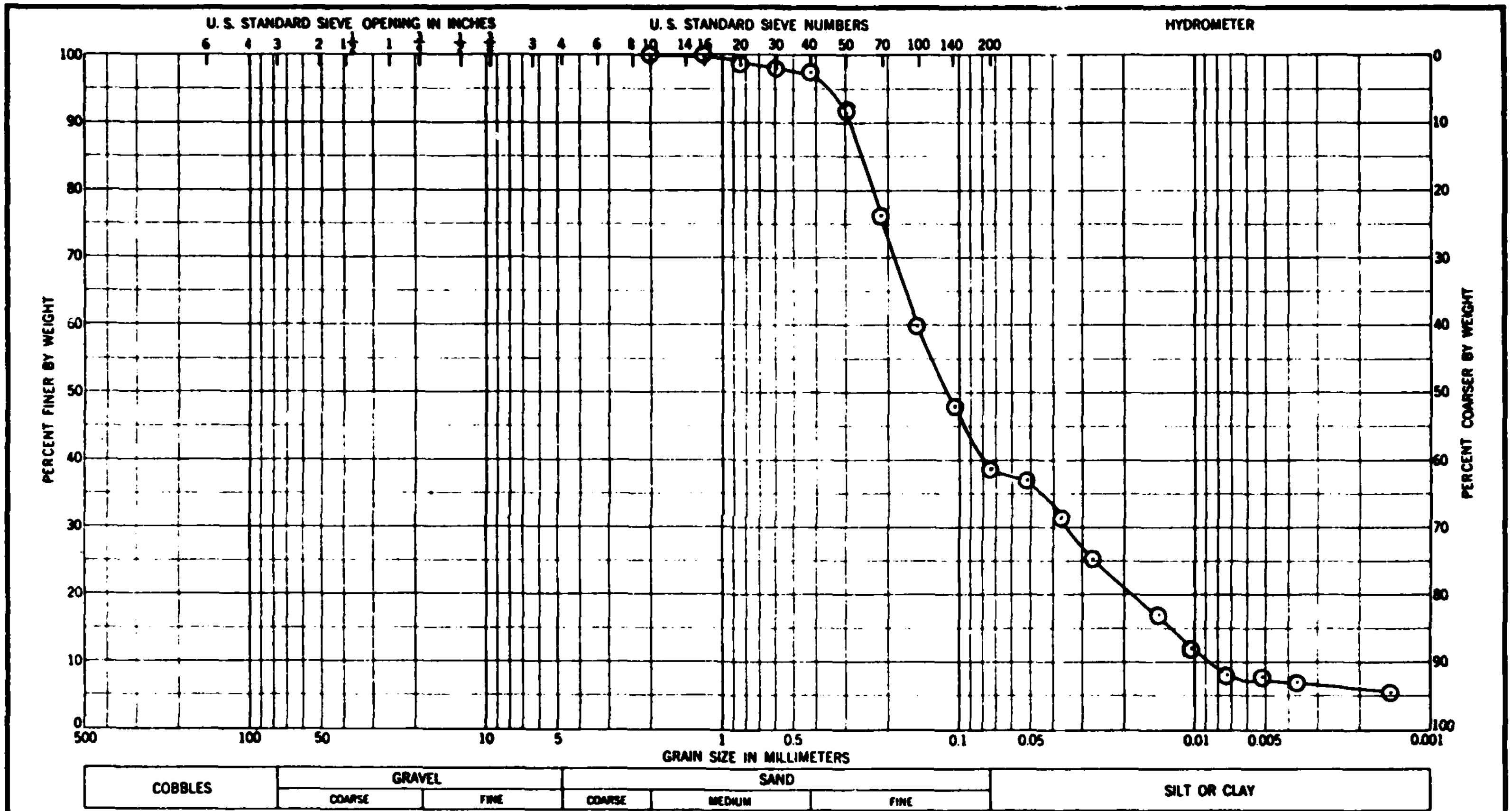


Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
IA	SURFACE	SANDY SILT (ML) DARK BROWN		NP		
		Gs = 2.62				
		ORG = 3.1 %				

GRADATION CURVES

Project	MBCE / DIRT III
	FORT POLK, LA
Area	X 0 , Y 30
Boring No.	BULK SAMPLE
Date	

Figure _ Representative grain-size distribution of native Fort Polk surface material



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
2	SURFACE	SILTY SAND (SM), DARK BROWN ORG. MATTER CONTENT = 1.5 % Gs = 2.64		NP		

Project	MBCE / DIRT III FORT POLK, LA
Area	X 65, Y 40
Boring No.	BULK SAMPLE
Date	28 AUG 80

GRADATION CURVES

Figure 4. Representative grain-size distribution of native Fort Polk surface material

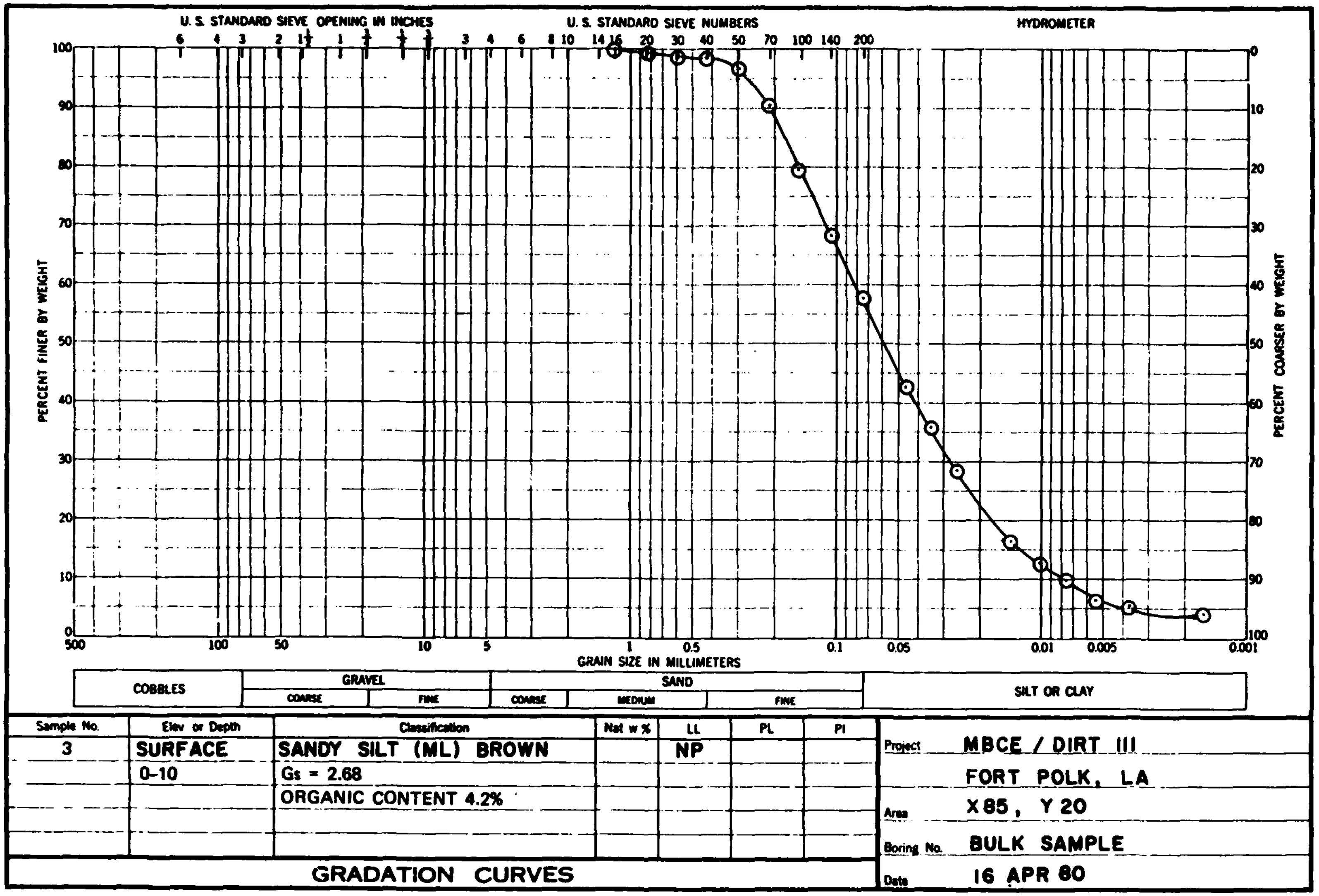


Figure 5. Representative grain-size distribution of native Fort Polk surface material

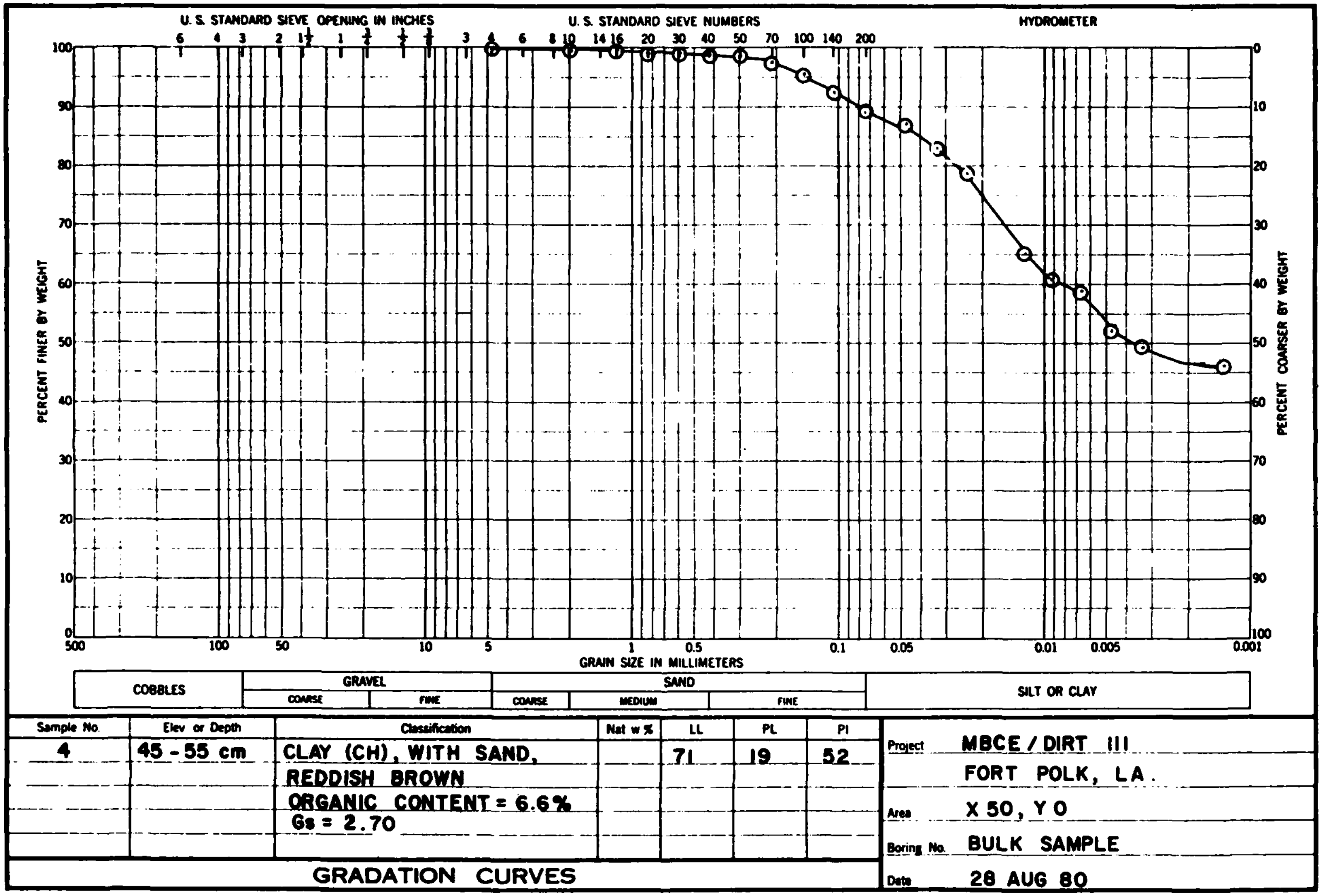
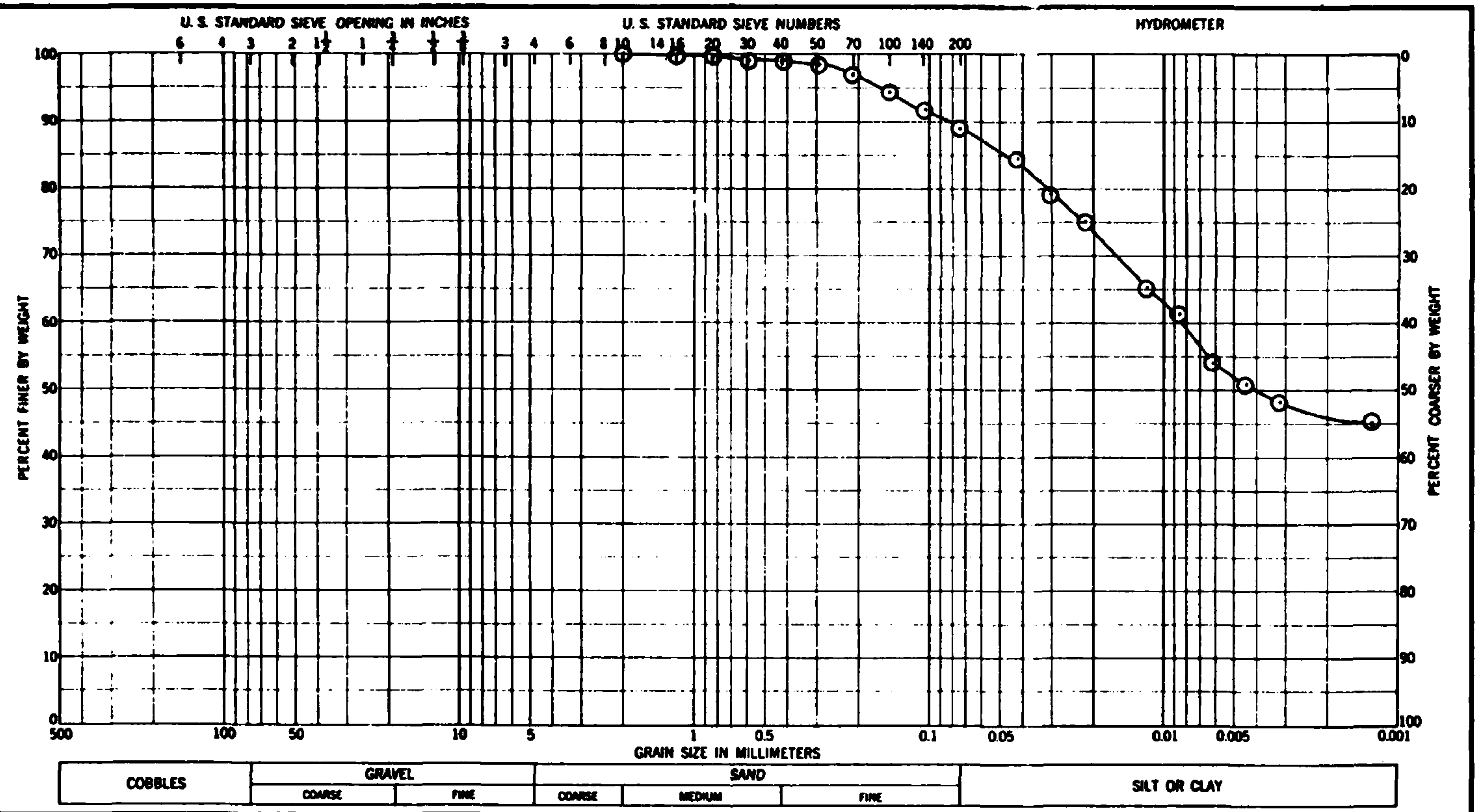


Figure 6. Representative grain-size distribution of native Fort Polk material 45-55 cm below surface

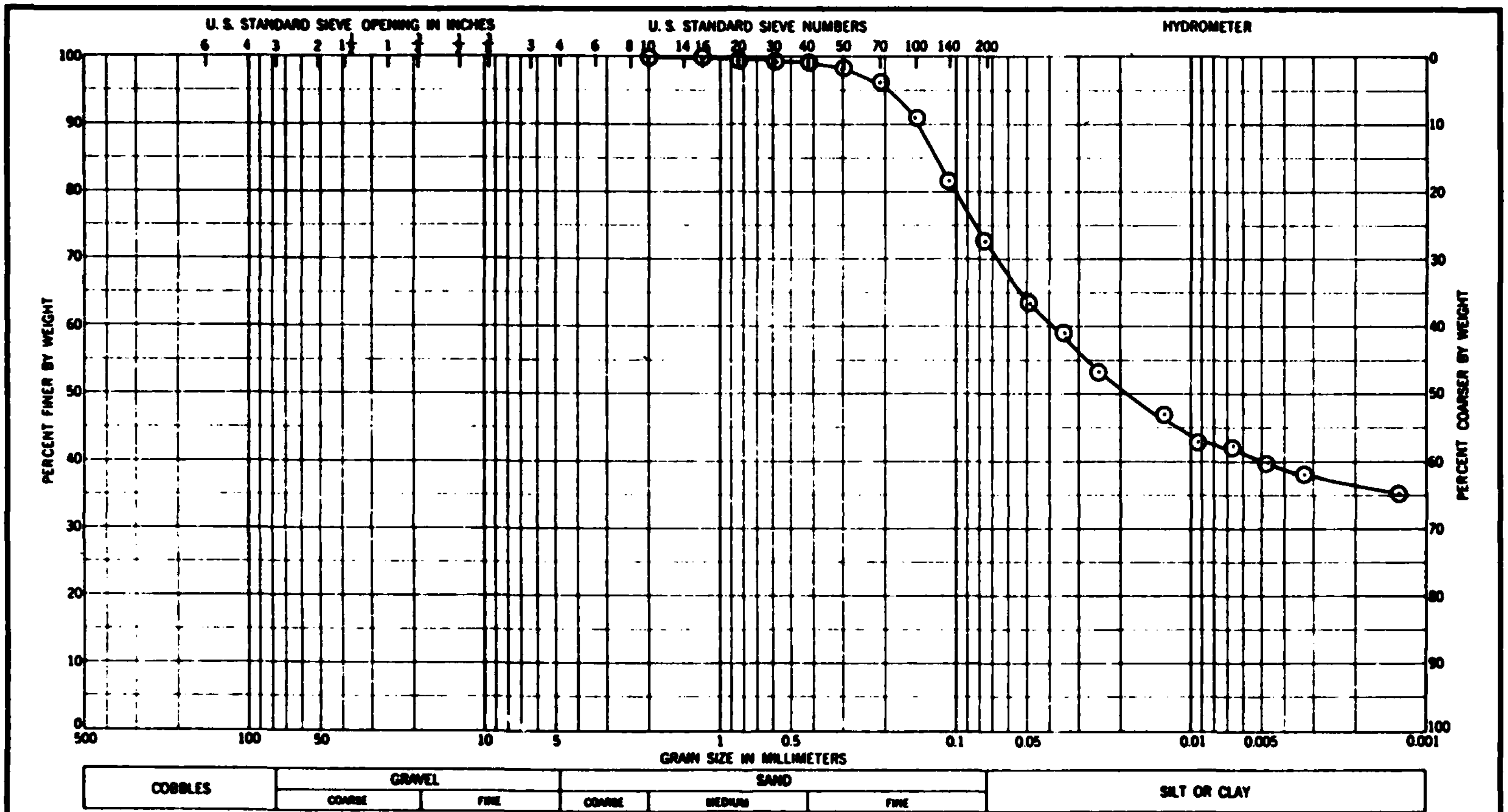


Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
5	60 cm	CLAY (CH), WITH SAND,		70	18	52
		BROWN				
		Gs = 2.70				
		ORG. CONTENT = 6.0 %				

Project	MBCE / DIRT III
	FORT POLK, LA
Area	X 60, Y 20
Boring No.	BULK SAMPLE
Date	28 AUG 80

GRADATION CURVES

Figure 7. Representative grain-size distribution of native Fort Polk material 60 cm below surface



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
6	60 cm	SANDY CLAY (CL), REDDISH BROWN		49	16	33

Project	MBCE/DIRT III
	FORT POLK, LA.
Area	X 85, Y 20
Boring No.	BULK SAMPLE
Date	28 AUG 80

GRADATION CURVES

Figure 8. Representative grain-size distribution of native Fort Polk material 30 cm below surface

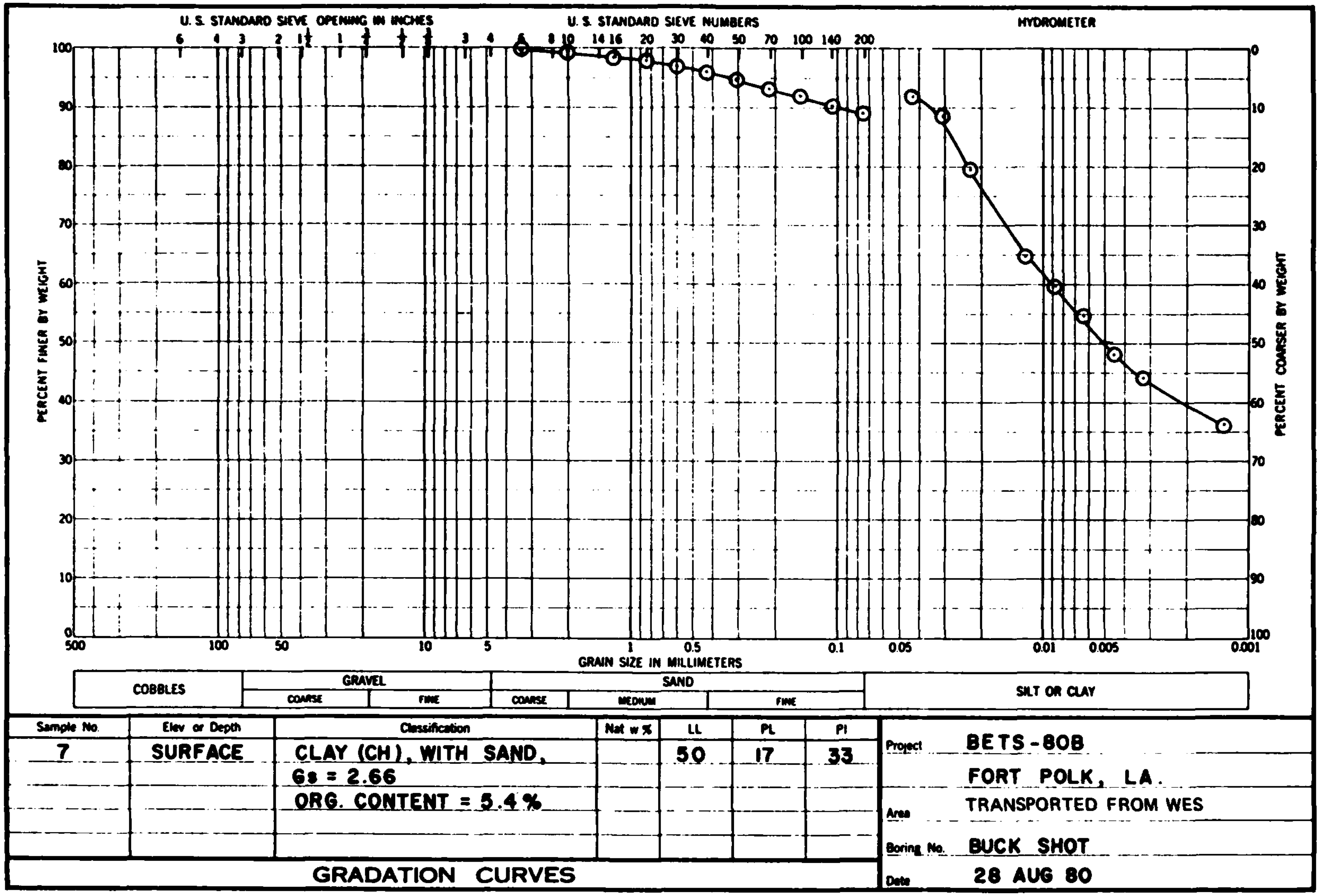


Figure 9. Representative grain-size distribution of tailored material hauled from WES to Fort Polk for BETS exercises

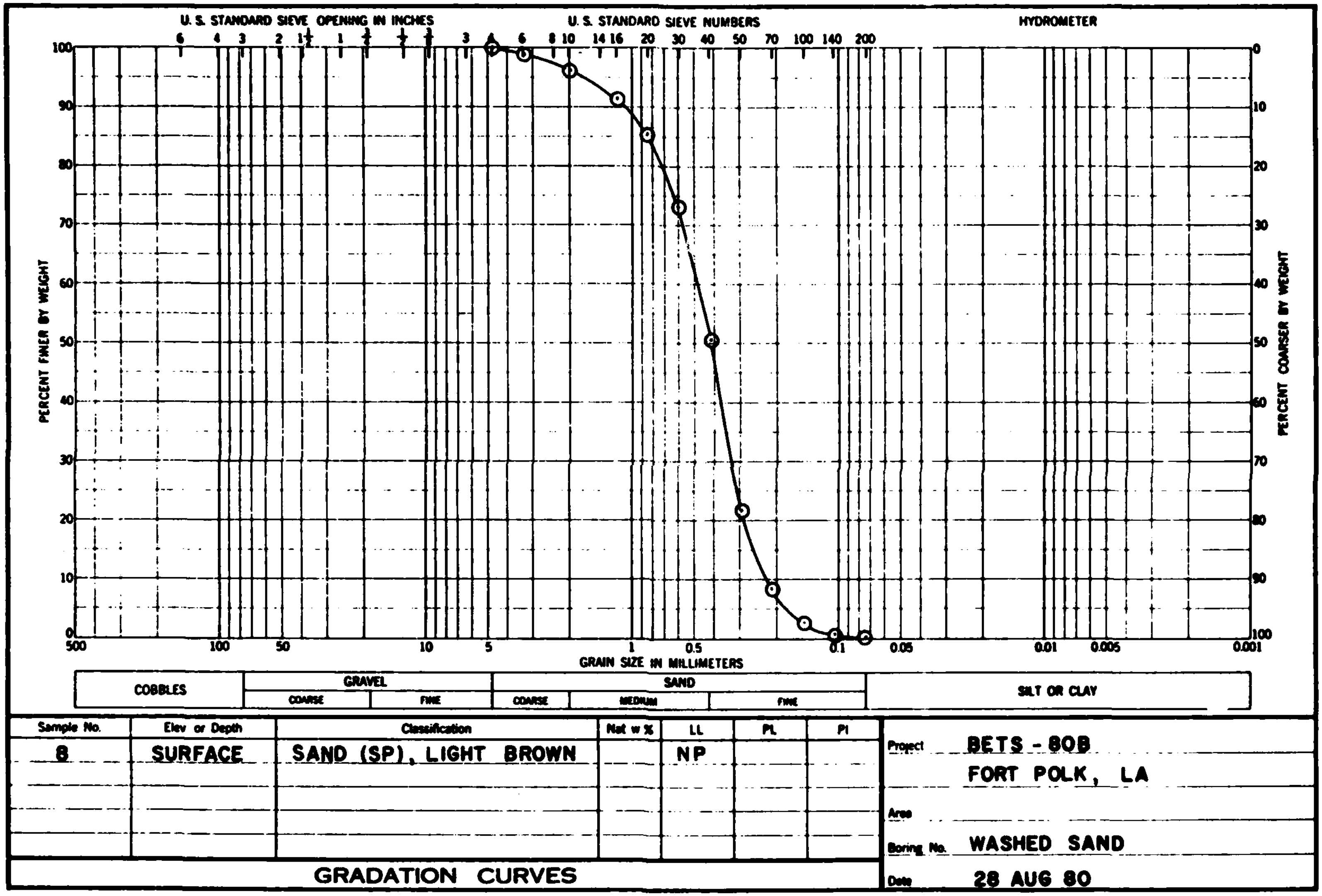
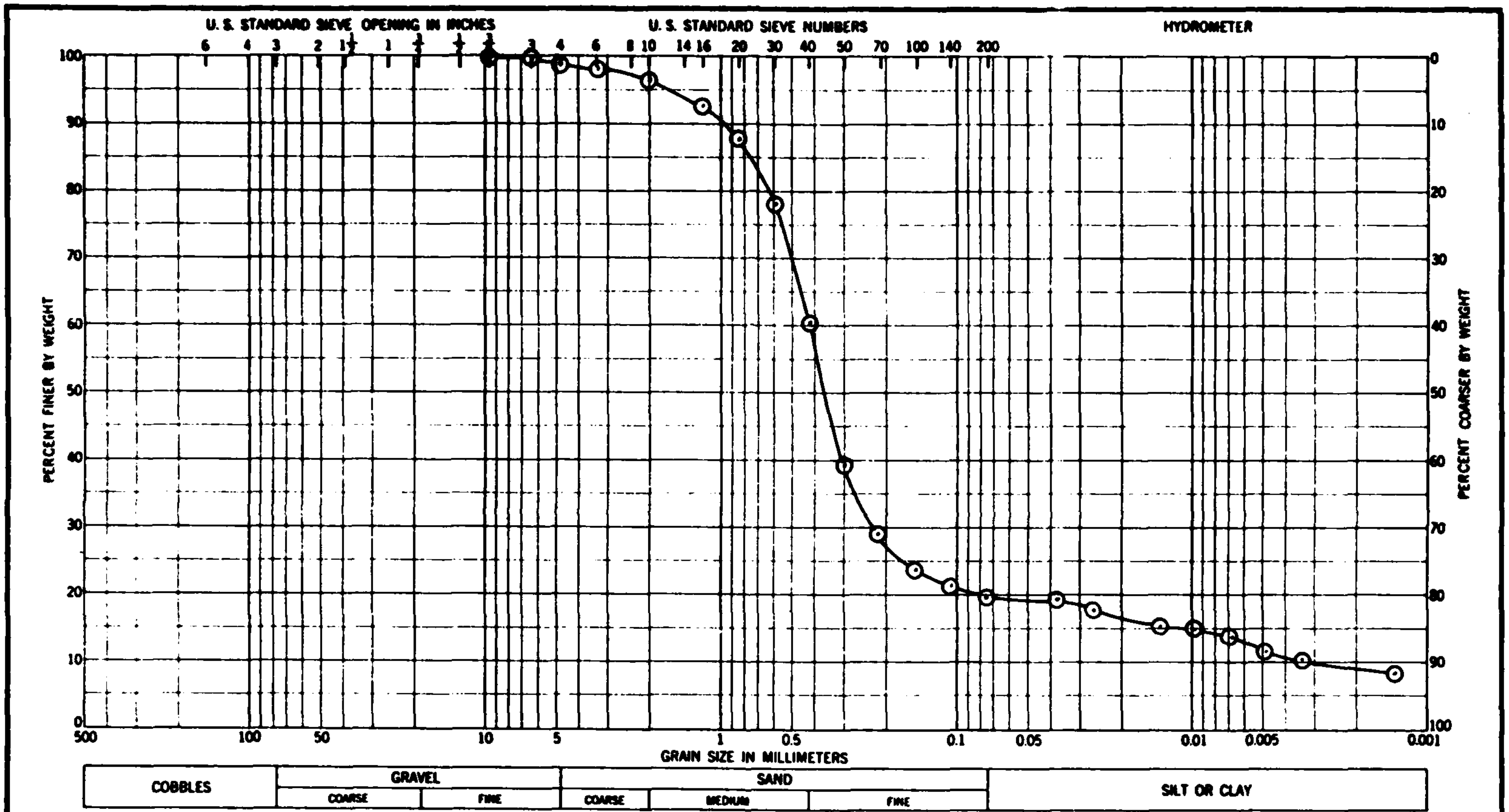


Figure 10. Representative grain-size distribution of tailored material hauled from Leesville, La., to Fort Polk for the BETS exercises



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
9	SURFACE	CLAYEY SAND (SC), BROWN		35	11	24
		Gs = 2.68				
		ORG. CONTENT = 3.1 %				

GRADATION CURVES

Project BETS-80B

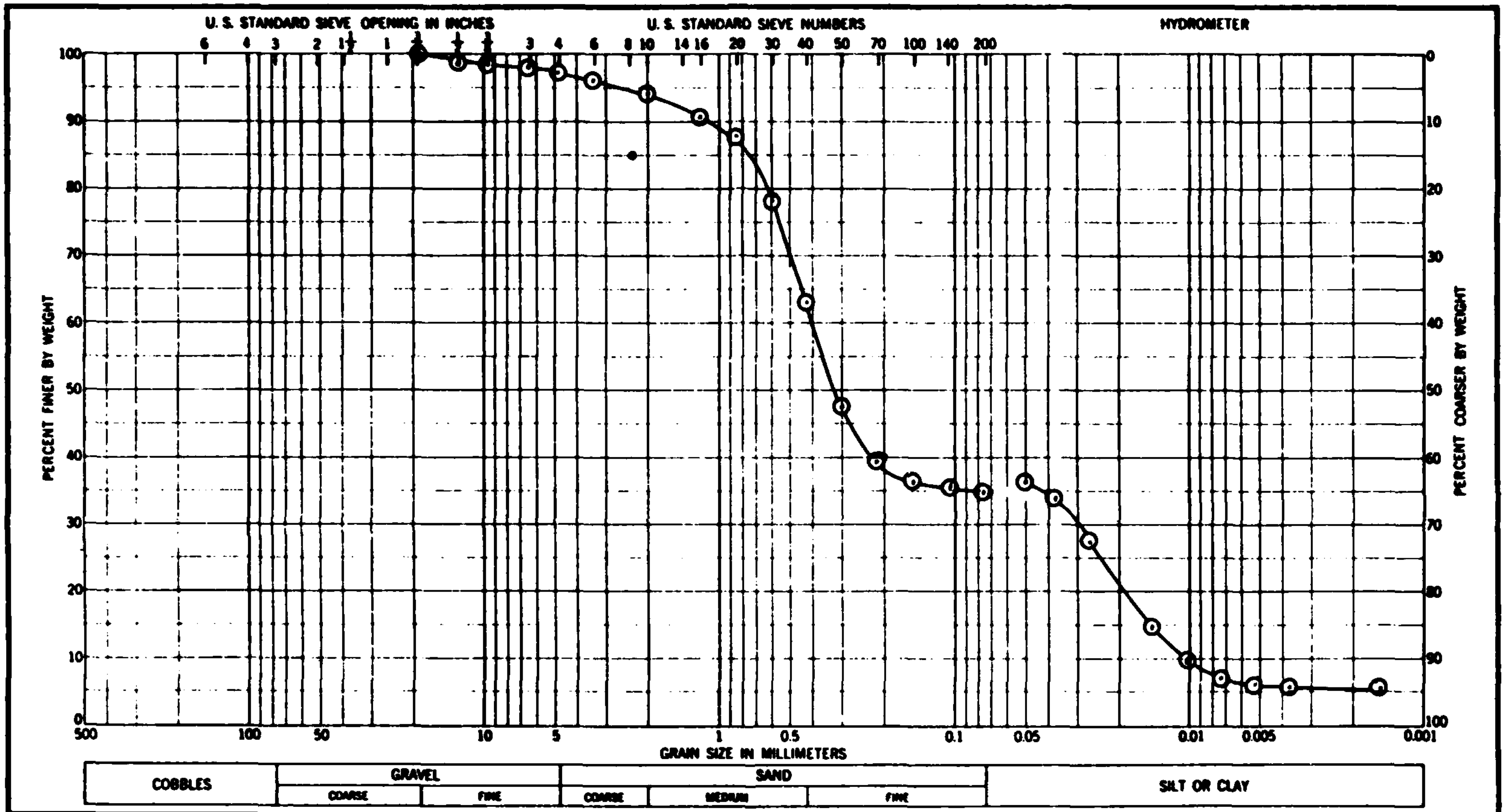
FORT POLK, LA

Area

Boring No. BLEND BUCKSHOT/SAND

Date 28 AUG 80

Figure 11. Representative grain-size distribution of mixture of material shown in Figures 9 and 10



Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
10	SURFACE	SILTY SAND (SM-SC), BROWN		19	13	6
		Gs = 2.68				
		ORG. CONTENT = 1.5 %				

Project	BETS-80B
	FORT POLK, LA
Area	X0, Y30
Boring No.	SILT-SAND MIX
Date	28 AUG 80

GRADATION CURVES

Figure 12. Representative grain-size distribution of mixture of material shown in Figures 10 and 13

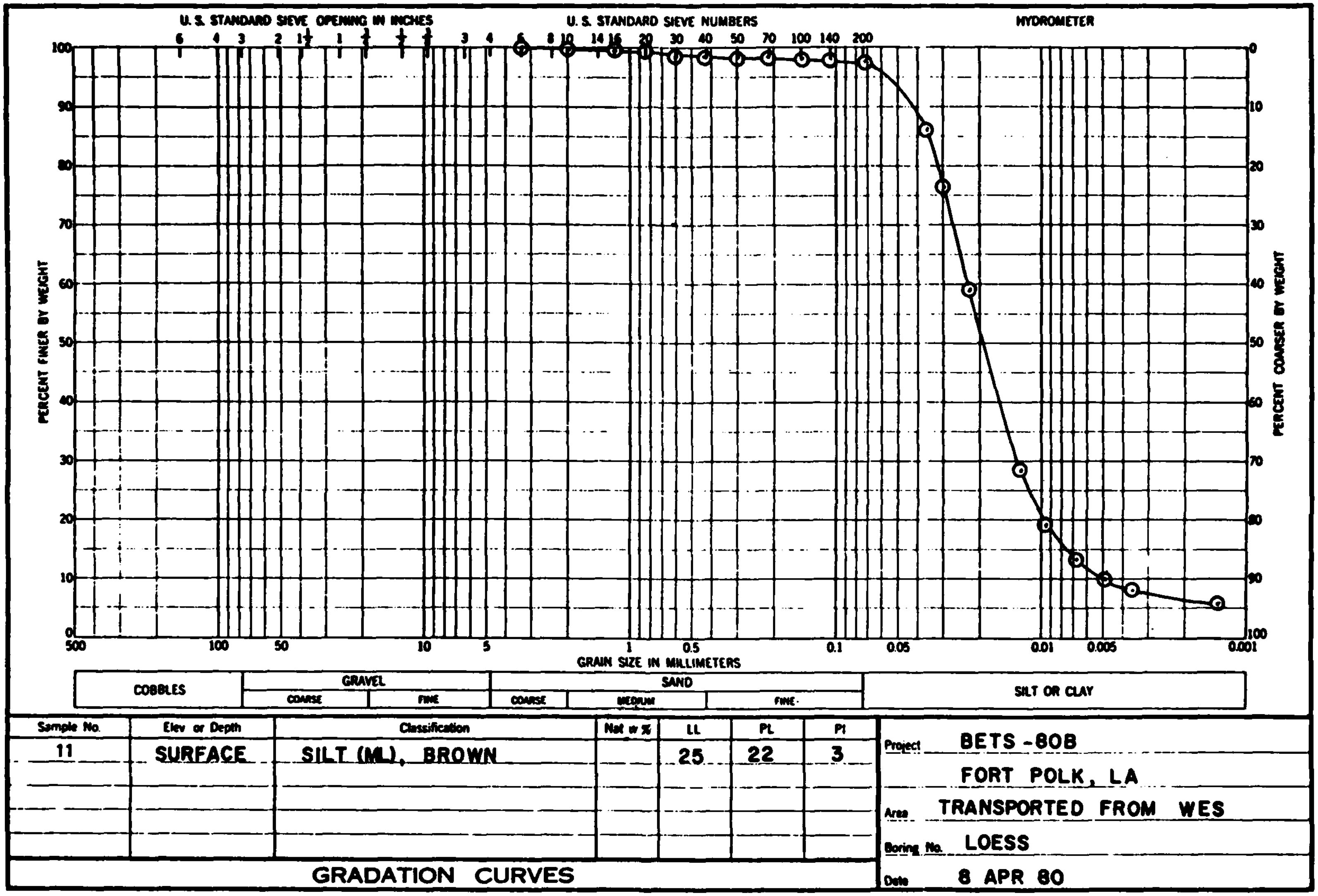
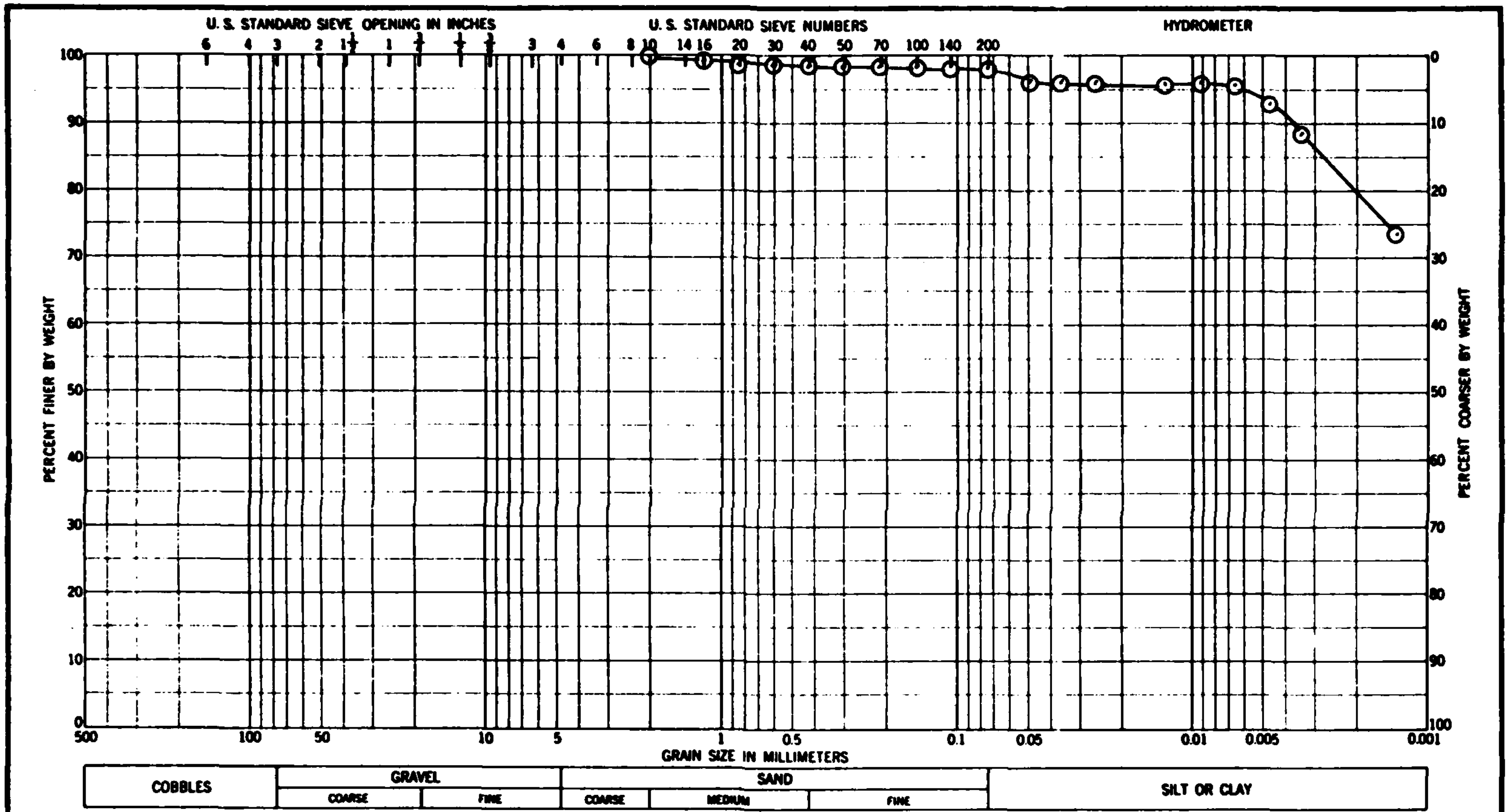


Figure 13. Representative grain-size distribution of tailored material hauled from WES to Fort Polk for BETS exercises



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
12	N/A	CLAY (CL), WHITE		49	28	21
		Gs = 2.68				

GRADATION CURVES

Project BETS-80B
FORT POLK, LA
Area
Boring No. KAOLINE, GA
Date 16 APR 80

Figure 14. Representative grain-size distribution of material hauled to Fort Polk for BETS exercises

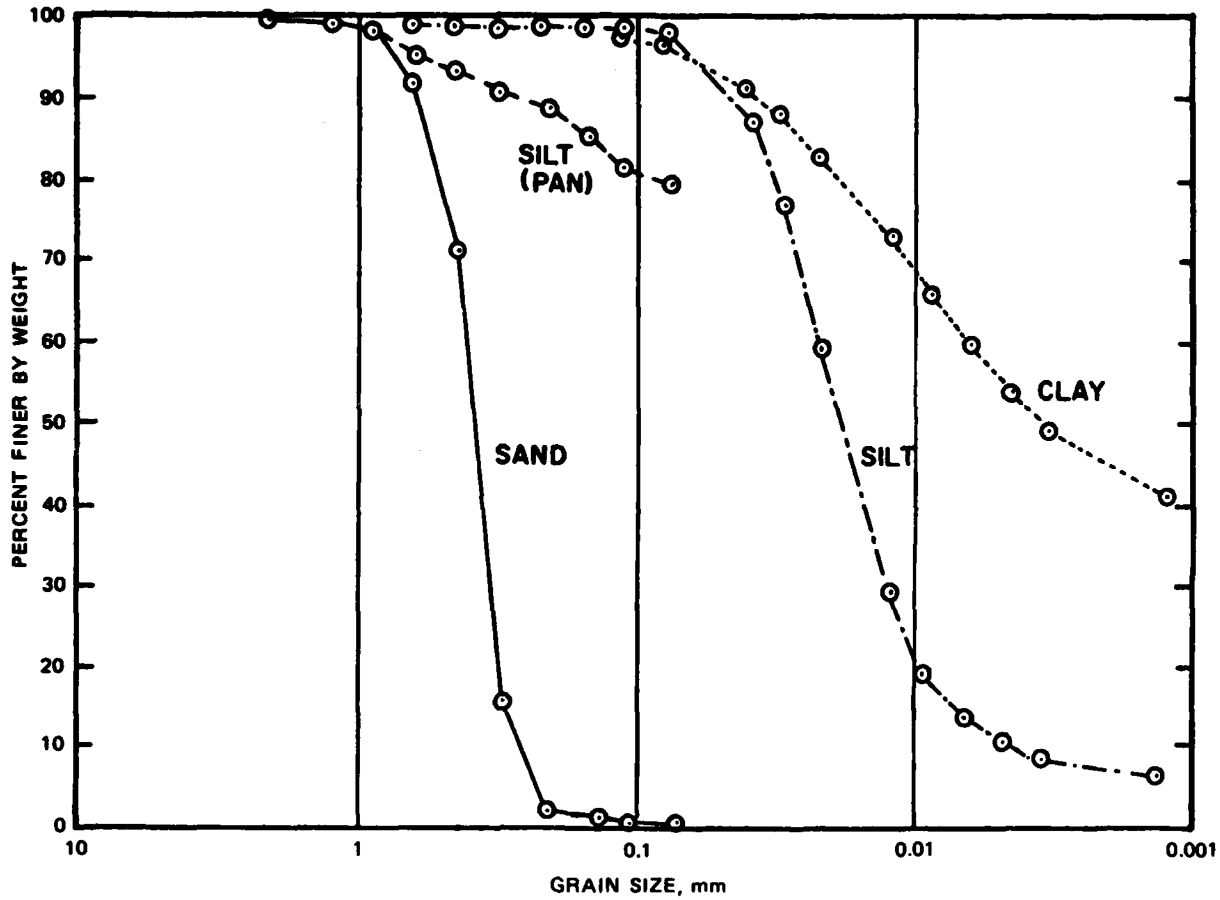


Figure 15. Comparison of gradation curves for soils used in the BETS exercises

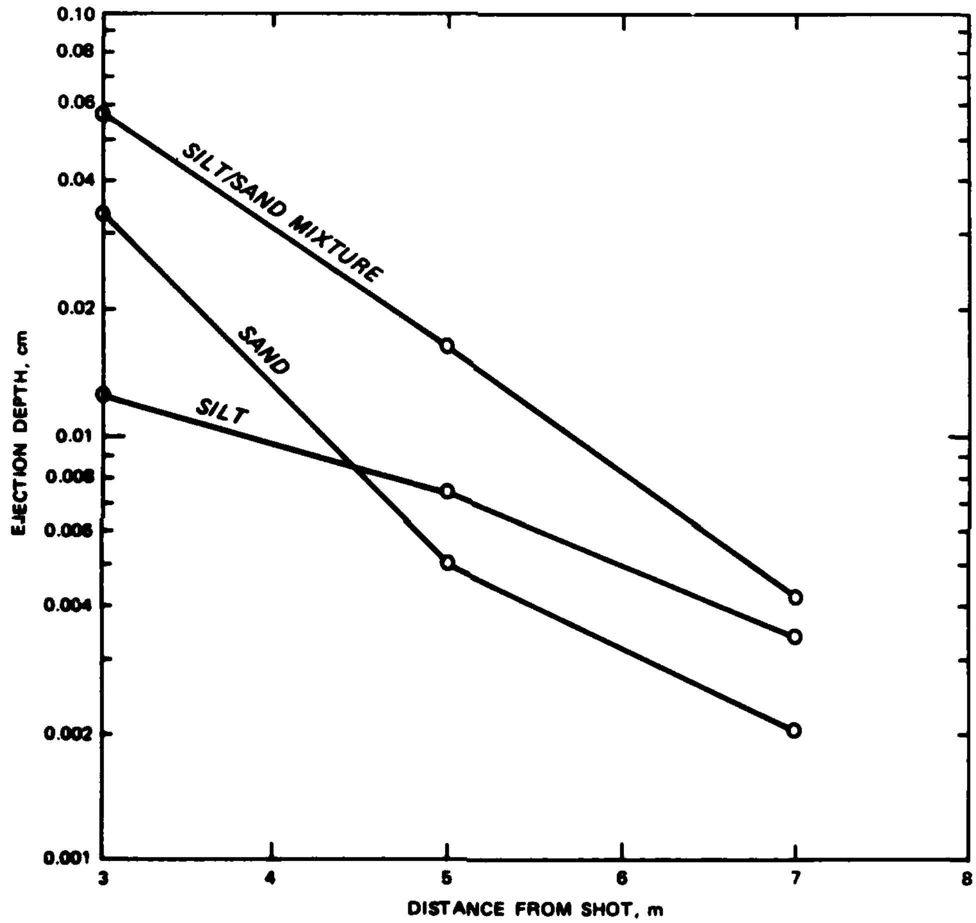


Figure 16. Comparisons of ejecta depths by soil type and distance from shot

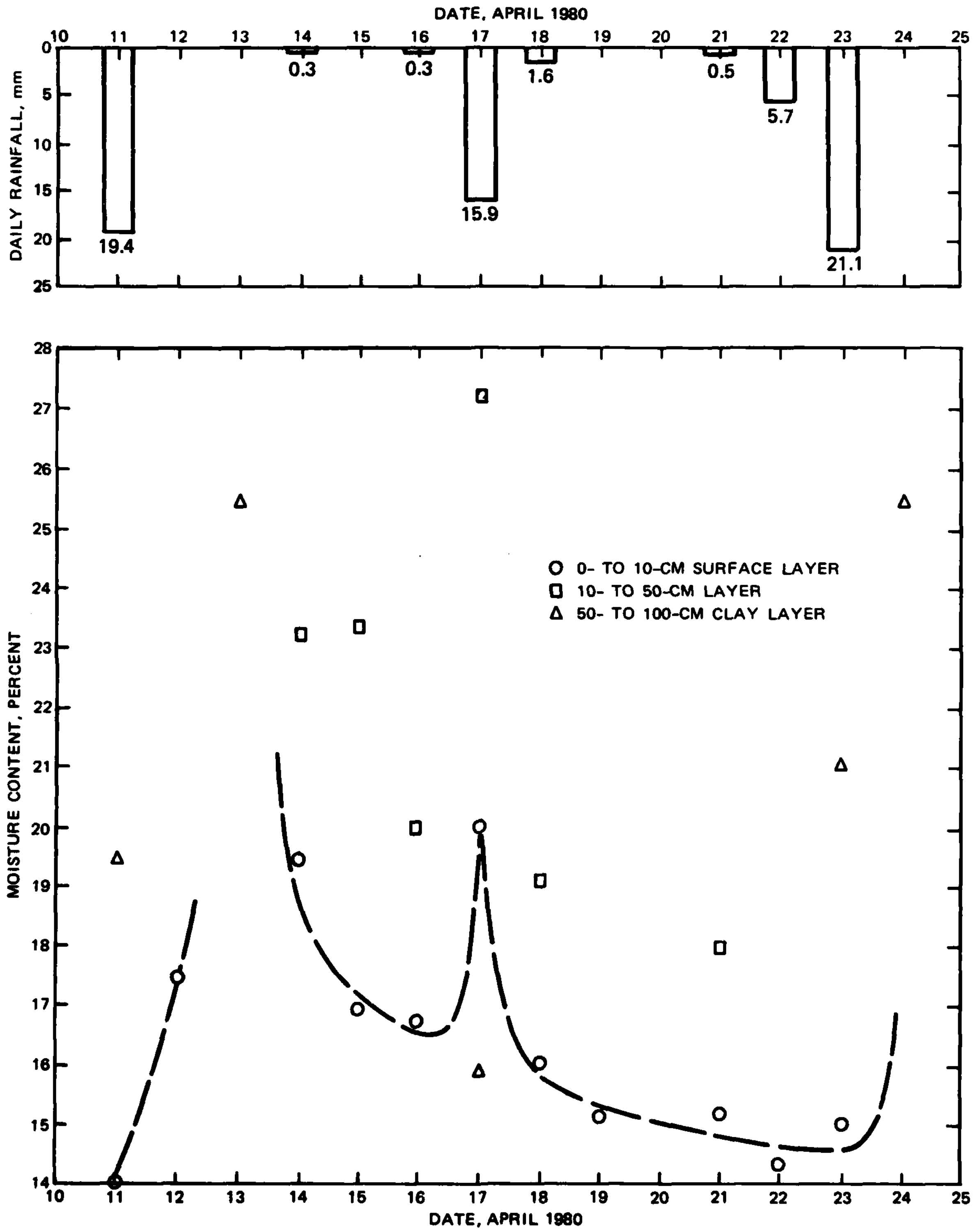


Figure 17. Average moisture contents for the three soil layers compared with daily total rainfall at the site from 11-16 April 1980

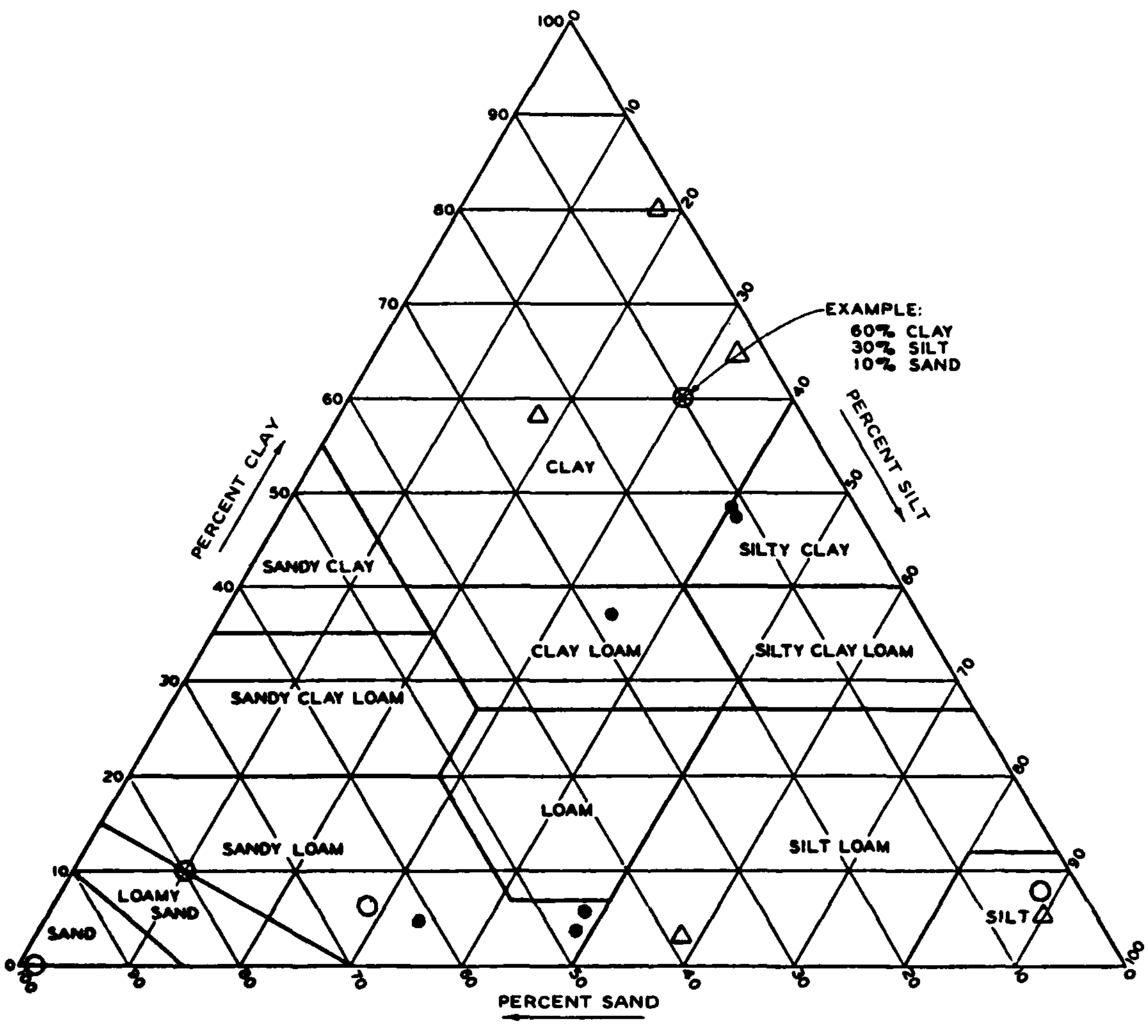


Figure 18. Placement of BETS soils in the USDA classification triangle

END

FILMED

11-83

DTIC